WATER REUSE AND ENVIRONMENTAL CONSERVATION PROJECT

CONTRACT NO. EDH–I–00–08–00024–00 ORDER NO. 04

RUSSEIFAH PHOSPHATE PILE (AREA 3) SITE REMEDIATION DESIGN REPORT

December 2014

IMPLEMENTED BY AECOM

December 2014

This document was produced for review by the United States Agency for International Development. It was prepared by AECOM.

WATER REUSE AND ENVIRONMENTAL CONSERVATION PROJECT

CONTRACT NO. EDH–I–00–08–00024–00 ORDER NO. 04

RUSSEIFAH PHOSPHATE PILE (AREA 3) SITE REMEDIATION DESIGN REPORT

DECEMBER 2014

Submitted to:

USAID Jordan

Prepared by:

AECOM

DISCLAIMER:

The authors' views expressed in this document do not necessarily reflect the views of the United States Agency for International Development or the United States Government.

TABLE OF CONTENTS

TABLES

FIGURES

APPENDICES

LIST OF DRAWINGS (APPENDIX E)

LIST OF ACRONYMS

AML	Abandoned Mine Lands
ASL	Above Sea Level
BOQ	Bill of Quantities
BSS	Basic Safety Standards
CFR	Code of Federal Regulations
DOE, USDOE	United States Department of Energy
EPA, USEPA	United States Environmental Protection Agency
FA	Feasibility Assessment
GAM	Greater Amman Municipality
GOJ, GoJ	Government of Jordan
H	Horizontal
IAEA	International Atomic Energy Agency
IDF	Intensity-Duration-Frequency
JNRC	Jordan Nuclear Regulatory Commission
JPMC	Jordan Phosphate Mines Company
MoEnv	Ministry of Environment
NORM	Naturally-Occurring Radioactive Materials
NRA	Jordan Natural Resources Authority
USAID	United States Agency for International Development
USNRC	United States Nuclear Regulatory Commission
RA	Radiological Assessment
RESRAD	RESidual RADioactive materials
RM	Russeifah Municipality
SRI	Superfund Redevelopment Initiative
STP	Standard Penetration Test
TENORM	Technologically-Enhanced, Naturally-Occurring Radioactive Materials
UMTRA	Uranium Mill Tailings Remedial Action
V	Vertical
VDD	Variable Depth Ditch
WRECP	Water Reuse and Environmental Conservation Project

AUTHORIZATION

This report is prepared as a sub-task of the USAID Jordan Water Reuse and Environmental Conservation Project (Project) to provide consulting engineering services to the Government of Jordan (GoJ) at specific targets consistent with USAID's Strategic Objective to achieve "Enhanced Integrated Water Resources Management."

Work on the Project is authorized under Order Number 4 in accordance with USAID Contract Number EDH-I-00-08-00024-00 for Global Architect-Engineering Infrastructure Services, as issued to AECOM Technology Corporation (AECOM).

1 INTRODUCTION

The USAID Water Reuse and Environmental Conservation Project works throughout Jordan in institutional capacity building, pollution prevention for industries, solid waste and wastewater management, and water reuse. The project is implemented by AECOM and a team of international and Jordanian partner firms. This five-year project has four primary tasks:

- Task 1 – Institutional and Regulatory Strengthening
- Task 2 – Pollution Prevention and Industrial Water Management
- Task 3 – Disposal sites Rehabilitation and Feasibility Studies
- Task 4 – Water Reuse for Community Livelihood Enhancement, including biosolids.

As part of Task 3, the project prepared a feasibility assessment (FA), identifying alternative techniques for rehabilitating the Russeifah site, and then, after an alternative has been selected, the project is to prepare design documents for the remediation. This report presents the results of the FA and the technical details of the remedial design.

The Russeifah site is composed of six individual contaminated areas. The contamination in each area is directly or indirectly the result of the development and operation of the phosphate mining industry, which began in the mid-1930s:

- **Tunnels:** The initial mining began with the hand excavation of exposed seams of phosphate-rich ore. This created a number of abandoned tunnels, called Area 5 (Tunnels).
- **Overburden:** In the mid-1950s, phosphate mining intensified through open pit mining. The material that lay on top of the phosphate-containing geological layers was removed. This material, called "overburden," was placed in a location now called Area 6 (Overburden Piles).
- **Phosphate stockpile**: During open pit mining operations, the phosphate ore was excavated and placed in a large stockpile near the phosphate ore processing plant. Throughout the intervening years, portions of the stockpile were processed and hauled off. However, the bulk of the pile remains and is called Area 3 (Phosphate stockpile).
- **Landfill:** As a result of the excavation of the phosphate ore, a large-deep open pit remained. In the mid-1980s, the Greater Amman Municipality (GAM) began using a portion of the open pit as a solid waste landfill. This landfill operation continued until 2003, when the landfill operation was curtailed. The resulting filled area of the open pit is referred to as Area 1 (Landfill).
- **Pit:** The unfilled area of the open pit is referred to as Area 2 (Pit).

- **Lagoon:** During the processing of phosphate, the process wastes were disposed of into a small wadi which drained to the Zarqa River causing sedimentation and complete blockage of the wadi. As a result, a storm water drainage lagoon was created, called Area 4 (Lagoon).

With the development of the phosphate mining industry, the town of Russeifah saw rapid population growth. As a result, the residential area is encroaching on Areas 3, 4 and 5, while businesses and industry are pressing on Areas 1, 2 and 6. None of the areas is now in direct use by the phosphate industry.

1.1 Problem Statement

Russeifah Area 3 (Phosphate stockpile) seen in Figure 1 consists of a large stockpile mainly of low-grade phosphate ore. The stockpile's volume is approximately 4.5 million m^3, and covers an area of 350,000 m^2. It is a result of aggressive open pit mining conducted between 1963 and the mid-1980's which caused this and other dramatic changes in the topography.

Figure 1. Phosphate stockpile

The phosphate ore stockpile has become an aesthetic, environmental and health concern over the years. It poses risks associated with slope stability and radiation hazards.

The average uranium concentrations in the ore material found throughout the site exceed the International Atomic Energy Agency (IAEA) exemption criteria and thus pose potential radiation threats to neighboring communities and future users of the site (IAEA 1996).

Slope stability analyses showed that the factors of safety for the representative sections were generally below the acceptable limits. This makes the greater part of the Area unsafe according to established criteria and presents the need for remediation measures to provide slope stability and radiological protection.

The Russeifah region continues to grow in population. There is a need to remediate the area not only from public aesthetics and environmental perspectives, but also from the perspective of beneficial use. The ultimate remediation of Area 3 (Phosphate stockpile) will improve the quality of life for the residents of Russeifah.

2 BACKGROUND

Prior to this design report, a feasibility assessment (FA) was developed by the Project team, submitted to USAID on 30 March, 2014, and was approved by USAID on 8 April, 2014. The FA was prepared based upon information available at that time. It provided background information about the site, existing conditions and other information obtained through topographic surveys, geotechnical investigations and radiological assessments. The FA also identified a set of site remediation alternatives and evaluated these alternatives against established criteria. The FA concluded with a recommendation for undertaking remedial measures with the stockpile in place. This design report is intended to build on the results of the FA and presently annexed radiological assessment reports (Appendix B, Parts 1 and 2) and present corresponding design objectives and components to facilitate the site's rehabilitation and reintegration with the urban fabric of Russeifah.

2.1 Site Description

The Jordan Phosphate Mines Company (JPMC) ceased mining operations in Russeifah in 1985 – leaving behind a massive stockpile of low-grade phosphate ore reaching a height of 40 meters at some locations. The pile has a volume of approximately 4.5 million cubic meters and covers an approximate area of 350,000 square meters (m^2). Upon initial storage of the low-grade phosphate ore, there was no intention of it remaining in place for such a long time. Therefore, no consideration and precautions were taken to account for side slope integrity or environmental health and safety.

Figure 2. Phosphate pile

In addition to the unstable side slopes (shown in Figures 2 and 3), public exposure to particulate technologically enhanced, naturally occurring radioactive materials (TENORM) is another major issue at the site. TENORM is produced when activities such as mining, or sewage sludge treatment, concentrate or expose radioactive materials that occur naturally in ores, soils, water, or other natural materials. Radioisotopes in TENORM include uranium-238 (^{238}U), thorium-232 (^{232}Th), radium-226 (^{226}Ra), and radon-222 (^{222}Rn), and other associated decay products.

Figure 3. Side slopes of phosphate ore pile

Over the course of time, the City of Russeifah has encroached on the site - such that the site is almost completely surrounded by urban residents, squatter communities, markets, and roads - putting workers, residents and commuters in the immediate vicinity at risk of direct exposure or inhalation of radioactive fugitive dusts. This necessitated that a radiological study be conducted by the Project team – the results of which were integrated to remedial design strategy presented herein.

The Area 3 (Phosphate stockpile) is to undergo rehabilitation with the aim of remediating issues related to both radiation and slope stability; and making the site suitable for re-development. The presented design is based on the results of the following:

- Topographic survey (Existing elevations are shown as screened contours in Appendix E, Drawings 1, 2, and 8, and as dashed lines in Drawings, 4,5 and 6)
- Survey of surrounding land use (Figures 4)
- Geotechnical investigation and slope stability analysis (See Appendix A)
- Radiological field assessment and air modeling analysis (See Appendix B1)

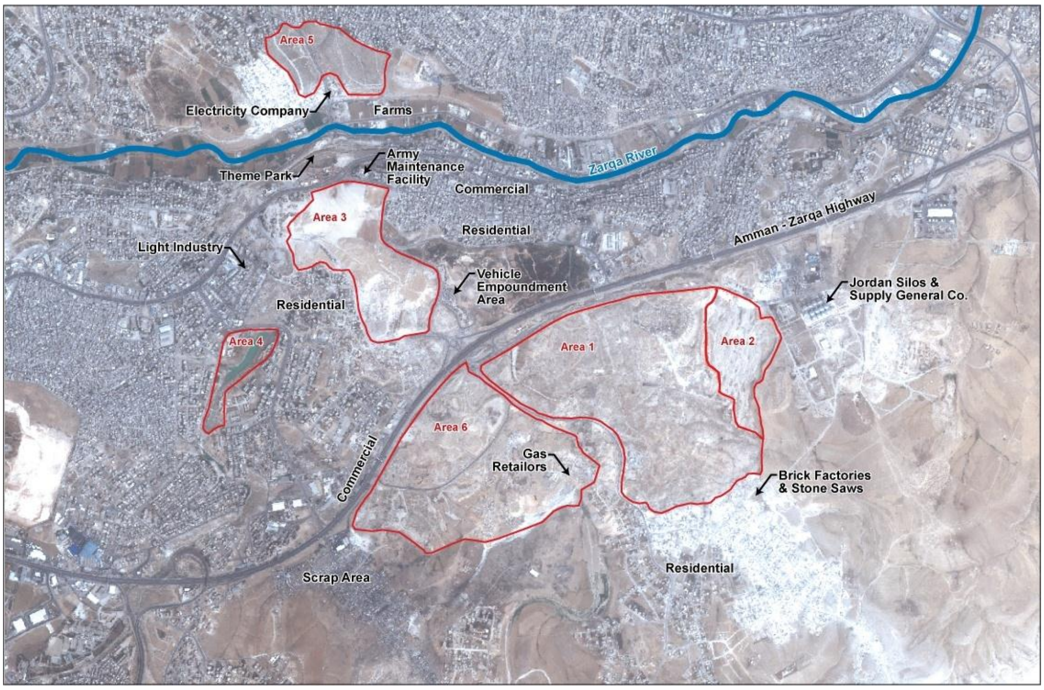

Figure 4. Land use surrounding areas of previous mining activities in Russeifah

2.2 Climate

The climate of Jordan in general is of East Mediterranean type, characterized by warm, dry summers and mild, wet winters. Since 2003, annual average temperatures in Ramtha (the nearest meteorological station to the study area) have ranged from 13 – 24.1°C, peaking in the month of August. Annual rainfall varies widely throughout the year within the area; with precipitation occurring during the winter months (October to May), while the summer months are essentially dry. The average annual precipitation is about 236.5 mm/year, and the area is classified as an arid region. Available climate measurements taken between 2003 and 2013 were averaged out and presented in Table 1.

Daily precipitation values from 2003 to 2013 were analyzed to calculate the mean monthly precipitation, as shown in Figure 5.

Table 1. Average data from Amman Airport Meteorological Station: E 35 59', N 31 59', Elevation= 780 m (2003-2013)

Parameter	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sept	Oct	Nov	Dec	Year
Mean Air Temp (ºC)	8.9	9.9	13.1	17.4	21.9	25.3	27.0	27.1	24.8	21.5	15.4	10.4	**18.6**
Mean Max. Air Temp (ºC)	13.2	14.4	18.4	23.4	28.3	31.4	32.9	33.1	30.9	27.3	20.7	15.1	**24.1**
Mean Min. Air Temp (ºC)	4.5	5.4	7.8	11.3	15.4	19.1	21.2	21.1	18.7	15.6	10.1	5.7	**13.0**
Total Rainfall (mm)	62.8	73.5	25.4	10.7	2.1	0.0	0.0	0.0	0.1	4.0	18.5	39.4	**236.5**
Mean Relative Humidity (%)	69.0	69.1	59.2	49.1	40.5	38.4	40.4	43.7	49.9	51.9	57.1	63.4	**52.6**
Mean Wind Speed (Knot)	4.8	5.7	5.5	5.8	5.9	6.3	6.7	5.6	4.6	3.5	3.1	3.9	**5.1**
Total Evaporation, Class 'A' Pan (mm)	52.7	63.9	110.6	166.5	245.5	301.3	326.1	289.4	224.3	159.4	87.7	59.8	**173.9**

Reference: Amman Airport Meteorological Station (2003-2013)

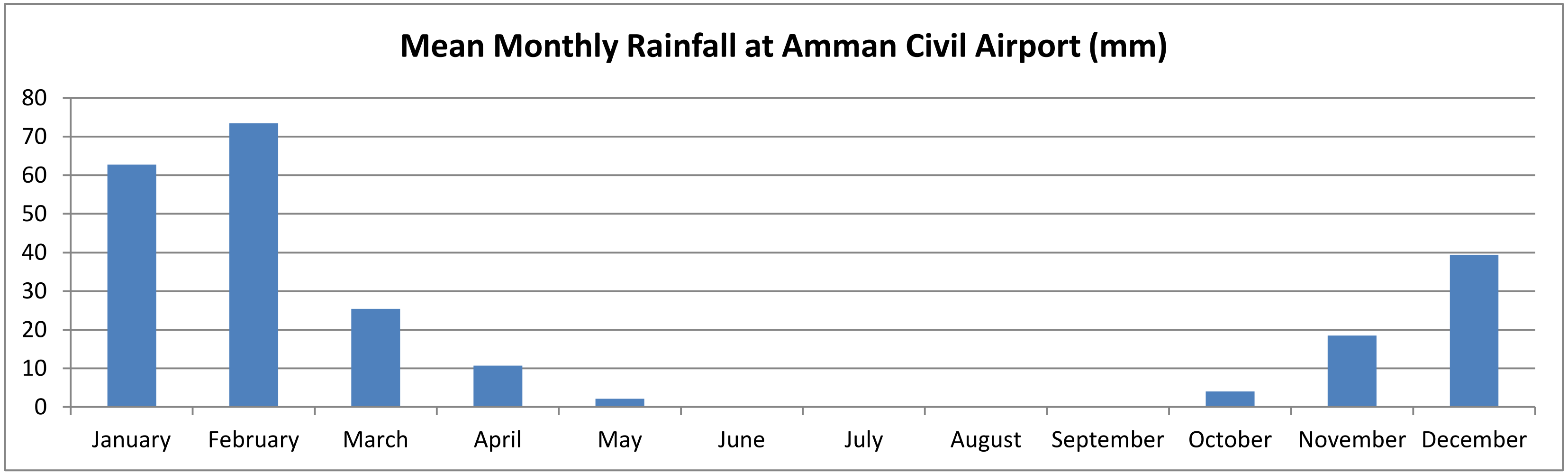

Figure 5. Mean monthly precipitation in the study area

3 FIELD INVESTIGATIONS

3.1 Geotechnical Investigation for Slope Stability Analysis

The geotechnical investigation, undertaken by the Project, presented the results and findings of the site investigation conducted to perform a slope stability analysis and determine the physical and chemical properties of the stockpile and surrounding earth. The study involved:

- The drilling of nineteen (19) boreholes (see Figure 6) and six (6) trial pits (see Table 2)
- In-situ testing (including standard penetration test)
- The collection of disturbed and undisturbed samples
- Laboratory testing

The scope of work consisted of the following:

- Collecting available information and maps pertaining to the project site; such as public services, site plans, land use maps, topographical and geological maps.
- Conducting site visits to the project site in order to identify the present land use, surface topography and geological features.
- Drilling of nineteen (19) boreholes in the project site to obtain disturbed and undisturbed samples and to carry out the required and appropriate lab tests.
- Excavating six (6) test pits. Along the slope profiles at specified approved locations.
- Conducting field tests such as Standard Penetration Tests (SPT) and field density in test pits.
- Providing daily progress reports.
- Conducting the necessary and applicable laboratory[1] tests.
- Preparation of the geotechnical report including findings, conclusions and recommendations.

Figure 6. Borehole locations in and around the phosphate stockpile used for the slope stability analysis

[1] These include classification and index tests (i.e. moisture content, specific gravity, bulk density, and particle size distribution), strength tests (i.e. uniaxial compressive strength, point load strength, and direct shear) and chemical tests (i.e. pH, sulphate, chloride, and carbonates organic matter). Tests were performed according to the relevant American Society for Testing and Materials (ASTM) Standards and/or British Standards (BS).

Table 2. Test pit coordinates used for the geotechnical investigation

Test Pit No.	Coordinates		Elevation (m)
	E	N	
TP01	36.039898	32.01053	665.5
TP02	36.03870	32.01191	706
TP03	36.03585	32.01310	697.5
TP04	36.03687	32.01046	677.7
TP05	36.03576	32.01190	705.5
TP06	36.03330	32.01215	686.5

The project site (Area 3) is totally covered by artificial fill materials composed of old excavated phosphate ore with approximate thickness ranging from (1) to (40)m. It is worth noting that **no groundwater was encountered in any of the boreholes down the drilled depths in Area 3.**

3.1.1 Slope Stability Analysis Methodology

Slope stability analyses were carried out for typical representative high slope areas at Area 3. The analyses were performed with the aid of GeoStudio/Slope-W 2007 software using the Bishop, Ordinary and Jonbu methods (ACES 2013).

Slope stability runs were performed taking into consideration the current conditions of the existing slope as well as other suggested remediation cases in order to improve the existing slope conditions. In the analysis, numerous circular failure surfaces were generated for each case (using a defined grid of circle centers and a range of defined radii) and the most critical surface with the minimum factor of safety were given. The model took into consideration material types, strength properties, and the geometry of the current and suggested slopes. The soil properties (unit weight and shear strength parameters) used in the analysis were selected based on 1) the empirical correlation between the SPT (N-value) test results and the internal angle of friction[2] (∅); and 2) direct shear test results of samples remolded at field density. Laboratory test results were subsequently used in the stability analysis. Used parameters are presented in Table 3.

Table 3. Material Parameters used in the Slope Stability Analysis

Material Type	Unit Weight (kN/m^3)	Shear Strength Parameters	
		c (kPa)	∅ (degree)
Fill materials	16.2	0	34

The analysis considered both static and dynamic conditions of the side slope and concluded that the required factors of safety in static conditions should be greater than 1.2. Seismic conditions, on the other hand, require a safety factor of 1.0 due to the absence of critical structure – thus, surface failure is most likely to be surficial. In order to evaluate the stability of the current slope conditions, seven (7) representative side slopes were selected for detailed slope stability analysis – the results of which are summarized in Table 4 (with reading locations presented in Figure 6 above). After study results of the existing conditions were obtained, a modeling exercise was conducted to determine the requisite grading to guarantee the geotechnical stability of the stockpile.

[2] For dumped fill (i.e. stockpile of tailings), the critical angle of repose presents a good estimate of the internal angle of friction

3.1.2 Results

3.1.2.1 Existing Slope Inclinations and Factors of Safety

Table 4. Existing Slope Conditions

Section/Profile	Maximum Slope Height (m)	Slope Inclination	Min. Factor of Safety
B1-B1A	46	1.51:1	0.951
B2-B2A	45	1.50:1	0.928
B3-B3A	29.5	1.45:1	1.124
B4-B4A	23	1.54:1	1.24
B5-B5A	20	1.50:1	1.324
B6-B6A	40	1:1	0.606
B7-B7A	30	1.4:1	1.202

The results show that the factors of safety are generally below the threshold of 1.2 and are thus unacceptable. Additionally, anticipated values in seismic conditions indicate additional decreases in slope stability.

3.1.2.2 Foundation Depth and Allowable Bearing Pressure

The nature of the site indicates that the allowable bearing capacity is primarily dependent on the expected differential settlement due to loads and heterogeneity of the materials. The geotechnical investigation (ACES 2013) cited the Jordanian Code of Foundations which recommends limiting the allowable bearing pressure to 0.4 kg/cm^2 (40 kPa) in the case of foundations on fill materials, while allowing for movement joints. In the event that the recommended allowable bearing pressure is insufficient for design purposes, the replacement of soil under proposed foundations presents itself as an option worth pursuing.

3.1.2.3 Compaction, Backfill and Filter Material Criteria

In the context of backfilling and compaction, the encountered fill material can be used as backfill but it is recommended that materials be of a soil/soil-rock mixture free of organic matter and other deleterious substances. Particle sizes shall not exceed 15 cm in the greatest dimension or be more than 12% larger than 7 cm. Fine materials (passing sieve 200) shall not exceed 35% and the plasticity index of the backfill material is not to exceed 10%. Backfill material shall be spread in lifts not exceeding 25 cm in un-compacted thickness with moisture conditioned to optimum moisture content. Furthermore, materials are to be compacted to a dry density not less than 95% of the maximum dry density as obtained by a modified proctor compaction test (carried out according to ASTM D 1557). Filter materials, on the other hand, shall be composed of clean coarse sand and gravel or crushed stone conforming to the following grading requirements presented in Table 5. These materials shall extend vertically from the bottom of the walls to a level of approximately 1m below the finished ground level behind the walls. The top 1m shall be backfilled with relatively impervious materials.

Table 5. Gradation Requirements of Fill Materials

Sieve Size	Percentage by Weight
2 ½”	100
1 ½”	80-100
¾”	60-95
No. 4	35-65
No. 8	25-50
No. 30	5-25
No. 200	0-3

3.1.2.4 Earth Pressure

Assuming no sustained surcharge, back slope, or hydrostatic pressure conditions the following soil parameters may be used in the design. (See Table 6).

Table 6. Soil Design Parameters

Test Pit	Unit Weight (kN/m³)	Cohesion (kPa)	Friction Angle (∅) (Degree)	Earth Pressure Coefficients		
				Active (K_a)	Passive (K_p)	At Rest (K_o)
TP01	16.2	0.0	32.84	0.28	3.54	0.44
TP02	15.8	0.0	34.25	0.27	3.69	0.43
TP03	15.4	2.6	33.78	0.28	3.54	0.44
TP04	15.9	0.0	40.49	0.21	4.81	0.34
TP05	15.2	7.55	30.70	0.32	3.13	0.48
TP06	16.7	0.10	40.71	0.21	4.81	0.34

3.1.2.5 Modeling

Based on the results of the investigation, the typical slope of ~1.5H:1V and the resultant factors of safety for existing conditions are unacceptable for long term conditions. The slope area was remodeled with a milder slope of 2.25H:1V. The results of the modeling exercise (see Table 7) indicated that a slope of 2.25H:1V or milder would be stable enough (in a geotechnical context) in static and dynamic conditions to support development activities.

Table 7. Modeling Results for Stability Analysis of 2.25H:1V Flattened Side Slope

Maximum Slope Height (m)	Slope Inclination (H:V)	Minimum Factor of Safety	
		Static	Dynamic
46	2.25:1	1.527	1.066

3.1.3 Recommendations and Conclusion

Existing slopes have a factor of safety of around 1.0 or less – which is typical for dumped fill slopes. However, upon erosion or excavation within these slopes, the factor of safety drops below 1.0, indicating failure condition. Some slopes appear to be stable due to factious cohesion of fine materials which readily disintegrate with movement and/or saturation. This calls for efforts to enhance slope stability through one or more of the following actions.

1. Flattening of side slopes to gradient 2.25H:1V or milder.
2. Stabilization by a 9.0m width geo-grid wall inclined at 65 degrees.

3.2 Topographic Survey

A topographic survey was performed in October 2011, to quantify the impact of the stockpile on the local landscape. The survey data was mainly used to design new site grading plans and to estimate the total volume and earth work needed. The total area that the site covers is around 350,000m^2 and consists of around 4,500,000 m^{3}of ore material. Elevations at the Area 3 site range from 665-710 meters ASL as shown in Drawings 4, 5 and 6 of Appendix E.

3.3 Radiological Field Assessment and Air Modeling Analysis

A radiological field assessment was carried out to provide an initial determination of the range of radiological risks from TENORM contained in the phosphate ore stockpiles and wastes present throughout the Russeifah Area 3 site. A second modeling effort was performed to gauge post-remedial conditions at the site; this is presented in Section 4.3.2.3 - Modeling for Remediation Planning. This section presents key points of interest pertaining to the radiological assessment--the complete study reports for existing and post remedial conditions can be found in Appendix B1 and Appendix B2, respectively. These radiological measurement and related modeling assessments evaluated the separate contributions to radiological exposure of workers and nearby residents contributed by:

- maximum rates of direct radiation from surfaces;
- inadvertent ingestion of contaminated soils; and
- predicted inhalation of fugitive airborne dusts from the Russeifah site.

The sampling and measurement plan included several types of complementary fully-calibrated field measurements to assess the potential exposures based on currently observed site conditions. In addition special construction activity simulation tests were combined with air transport modeling to estimate the potential added exposures that might occur from future construction activities. These would likely involve loading and transport of ore materials from the site and/or the possible addition of protective cover materials. Air modeling considered both short-term simulated inhalation exposures to workers and long-term potential exposures to public areas.

The scope of the radiological assessment included the following activities:

- **An external radiation survey** at 151 locations to assess the total external dose rates present throughout the site, including natural local background levels.
- **A gamma walkover survey** to map the relative external radiation exposure contributions from TENORM surface soil concentrations present throughout the site. One reading was taking per second while walking in parallel lines (10 meters apart) at a speed of 1 meter per second.
- **Soil sampling and analysis at 27 locations** to:
  - Correlate the survey instrument response to surface radioactivity levels
  - Characterize the radionuclide concentrations and properties of the materials found on the site, including the stockpiles and any surrounding contamination
- **Environmental air sampling**, using high volume air samplers to assess airborne concentrations of re-suspended TENORM. Air samples were taken at the site boundary and in the vicinity of simulated construction activities (excavation, loading). Five ambient samples were collected during a normal pre-operation day and another five were collected over two days of simulated construction activities, to support a preliminary assessment of current vs. potential compliance with public and occupational airborne concentration limits.
- **Personal air sampling** (using lapel samplers) to measure breathing zone airborne TENORM exposure to workers during construction activities simulated at an Ore Loading Operations area. These were fully documented in the Appendix B1 report. **Radon sampling** using 150 canisters to characterize radon emanation rates present in the different previous use areas.
- **Air modeling** of potential worst case exposures from fugitive dusts was performed using a short-term air transport simulation model (SCREEN3) to compare with field measurements and to support estimation of maximum annual average airborne exposures to workers and visitors. A more refined long-term simulation model (AERMOD) was used to predict the maximum annual fugitive dust exposures to nearby neighborhood residents. (Estimates for long-term exposures to any workers

having long-term assignments at the site are also more accurately estimated by this more refined modeling method.)

- **Radiological dose and related risk assessment (screening analysis)** of likely exposure scenarios in the vicinity of the study area.

3.3.1 Methodology

Table 8 lists the instruments and equipment used for the aforementioned studies.

Table 8. Survey Instruments and Equipment

Use	Type
Dose rate survey	Tissue equivalent proportional counter
Gamma walkover survey	Sodium iodide (NaI) scintillation detector
	GPS with data logger
Swipe counter	Alpha/beta scalar with ZnS(Ag) scintillation detector
Radon sample canisters and counter	Charcoal absorption canisters and 3” NaI scintillation detector well counting system
Area air samplers	Intermediate volume air sampler
Personal air samplers	Lapel air sampler

In order to obtain representative data during surveying and sampling, the Area 3 site was broken into three separate areas for evaluation and a background area based on the different conditions found in each. (See Appendix B1 report and its Appendix A for details). The four areas were as follows:

- **Ore Stockpile Area**: This area consists of the stockpiled, unprocessed ore material. The area appears to be composed of one large pile of ore with an approximate area of 166,000 square meters and a height of approximately 25-40 meters above grade. The stockpiled ore material ranges in size from fine materials (dirt or dust), to gravel (1-2 centimeter diameter), to larger rocks (~30-50 centimeter diameter).
- **Fine Aggregate Processing Area**: This area consists of piles of processed ore materials. The ore material appears to be the result of mechanical grinding of ore material, resulting in the fine, dust-like ore aggregate stockpiled in this area. The fine aggregate is stockpiled in multiple mounds ranging in height from one to three meters. The total area encompassing the fine aggregate piles is approximately 11,000 m^2.
- **Park Area**: The Park Area is approximately 65,000 m^2 of compacted ore material. The area is relatively flat and level with the adjacent King Abdallah I road. The eastern portion of the park contains a football field. A small area (~2,000 m^2) adjacent to King Abdallah I road is covered with a two to four centimeter thick layer of dark soil.
- **Background Area**: The background area for external exposure measurements was a field area approximately one kilometer east of the site. (The refined air transport modeling reported below suggests that this area may still receive some inhalation dose contributions from airborne fugitive dusts when the mining site is upwind).

Survey, sampling and modeling results were then used in a dose modeling (screening) exercise to identify receptors and assess exposures from the ore stockpiles and process materials at the site. The following receptor groups were studied.

- **Outdoor Worker.** This long-term receptor is a full-time employee of the site owner. This receptor spends most of the workday outdoors conducting various activities. For this assessment, the outdoor worker is not primarily involved with construction activities (e.g. excavation/loading of ore material). This receptor is exposed to surface and shallow subsurface soils. This receptor is exposed via incidental ingestion of soil, inhalation of fugitive dusts, and external exposure to contaminant radiation emissions. The applicable IAEA-recommended dose limit of 20 mSv/year assumes that this worker has training in procedures to control radiation exposures (IAEA 1996, 2004).
- **Construction Worker.** This is a short-term adult receptor that is exposed to soil contaminants during the work day for the duration of a single construction project (typically a year or less). If multiple non-concurrent construction projects are anticipated, it is assumed that different workers will be employed for each project. The activities for this receptor typically involve substantial on-site exposures to surface and subsurface soils. The construction worker is expected to have a very high soil ingestion rate and is assumed to be exposed to contaminants via the following direct and indirect pathways: incidental soil ingestion, external exposure to radiation emissions, and inhalation of fugitive dust. Again, the applicable IAEA-recommended dose limit of 20 mSv/year also assumes that this worker also has training in procedures to control radiation exposures.
- **Park Visitor.** This is a short-term child resident receptor exposed during short duration (4 hour) visits to the park area of the site one evening per week. The activities of the receptor include playing, eating, and drinking on the site. This receptor is exposed to ore material via incidental soil ingestion, external exposure to radiation emissions, and inhalation of fugitive dust. The applicable IAEA recommended dose limit for children and other sensitive members of the public is 0.5 mSv/year (IAEA 1996).
- **Off-site Resident.** The off-site resident is exposed to contaminants transported off-site, both during and after construction, for a total of 30 years. This receptor is assumed to have no direct contact with on-site soils. Thus the only exposure pathway evaluated for this receptor is the inhalation of fugitive dust, which is likely to be somewhat exacerbated during periods of short-term construction as a result of dust generated from related activities. The applicable IAEA-recommended dose limit for adults is 1.0 mSv/year; but for children and other sensitive members of the public is 0.5 mSv/year (IAEA 1996)
- **Farm Market.** This receptor area was considered as a special case of interest, as it is almost surrounded by the elevated stockpile area at the eastern end on the Russeifah site. It is assumed that adults working there may be members of the public who visit that area for up to 10 hours a day for the work week, a similar exposure period to the Outdoor Worker. Their annual exposure estimate is adjusted to reflect the potential inhalation of fugitive dust from the surrounding stockpiles. Since this is considered a public area, where workers are not trained regarding radiation exposure precautions, it is assumed that the IAEA-recommended limit for an adult will apply (IAEA 1996).

The three exposures routes contributing radiation dose to the receptors—direct external exposure, inhalation, and ingestion—were evaluated to find a “worst case” dose for each and subsequently judge the current and potential future status of the TENORM-contaminated site.

3.3.2 Results

The average ^{238}U concentration in the ore material found throughout the site (1,154 ± 239 Becquerel per kilogram (Bq/kg) was greater than the IAEA exemption criteria of 1,000 Bq/kg (IAEA 2004). Given that the ore material at the site does not meet this IAEA exemption criteria, the radiation protection guidelines and limits are applicable for future planned activities at the site and cannot be excluded without an appropriate evaluation of proposed activities at the site and potential remediation needs to facilitate intended uses. Therefore, the radiological evaluations described in this report and the RA were conducted. Detailed results from the RA can be found in the full report as presented in Appendix B1. The gamma walkover survey results show that the radiation emission rates and underlying soil and ore uranium concentrations are relatively uniform throughout the site. The soil samples taken at various area locations are considered representative of the entire site. The results also provide the concentrations of TENORM radioisotopes in the source terms used in the dose evaluations.

The predicted long-term exposure doses for only one of the five types of exposure scenario receptors analyzed —the maximum Off-site Resident—exceeded the annual dose limit for members of the public of 1 milliSievert (mSv) by a significant margin, with a maximum value close to 6 mSv per year (mSv/year). Fortunately, that location is in a primarily industrial location with few residences present.

Most **Off-site Residents**, even those close to the facility boundaries, under the current conditions, were predicted to have annual exposure dose rates at least a factor of three lower than the maximum case of 5.95 mSv/year, or less than 2 mSv/year. Only one very close neighborhood to the northeast of the site may experience these annual dose rates on the order of 6 mSv/yr. However, it should be emphasized that these higher levels are model predictions driven by potential transport and inhalation of fugitive dusts eroding from the stockpile areas. The recent study did measure the concentration of the soils and the direct radiation from the surface gamma and radon exposures in one off-site area (assumed to represent a relative “background” location. However, it was beyond the scope envisioned for this 2012-2013 screening study (Appendix B1) to characterize dust emissions reaching more distant residential locations under a wide range of meteorological conditions. Such an analysis would require a long-term air monitoring program.

Based on early public concerns, the particular exposures to the neighborhood of several homes on the south western side of the stockpile region (virtually within the site) were reviewed, and according to the dose mapping exercise**,** they had predicted exposures within +/- 20% of the IAEA dose rate guideline for adults of 1 mSv/year. This would not be generally considered a significant deviation from that guideline. However, for non-school children spending 100% of their time in this neighborhood, the inhalation exposures would likely exceed the recommended 0.5 mSv/year limit. The IAEA limits allow annual public exposures above 1 mSv/year if the average over five years is below 1 mSV, and the maximum dose in one year is less than 5 mSv. Although virtually all but one location for predicted doses is below 5 mSv per year, over 90 percent of these estimated doses are a result of re-suspension of the ore material (wind erosion) that comprises the entire site. Thus management of erosion is the key to lowering all predicted results.

The **Park Visitor**, who is also identified to be a resident child, is the least exposed of the evaluated scenarios, due to the relatively short duration and limited frequency of assumed exposure times. The total annul exposure of 0.06 mSv/year for this activity scenario is insignificant, especially when compared to the same individual’s exposure while at home, if the residence is within a few hundred meters of the site boundary (as described above).

Additional interest in the potential exposures at the livery **Farm Market** area on the southeast edge of the stockpile area led to more careful analysis of those calculated exposures. Site and vicinity annual exposure dose prediction models indicate that dose rates might be in the 2 to 3 mSv/year range if occupied 24 hours/day; but the more limited time assumed for daily visits there leads to a calculated exposure dose from inhaled U^{238} that is 0.96 mSv/year, just slightly below the 1 mSv/year limit for adult residents.

Similarly, for the **Outdoor Worker** who regularly works in either the present Park area, or who may work part of the time in any area of the stockpile developed for recreational purposes in the future, calculations show that this worker would be expected to experience exposures resulting in a total dose of 0.94 mSv/year. This dose is also just below the IAEA guide for adult residents, even though as a (trained) worker, the applicable guideline is 20 mSv/year. (IAEA 1996, 2004)

For the **Construction Worker** considered in this analysis, both the measurements reported for the simulation tests, as well as the short and long-term exposure doses calculated with the two models, indicate that the maximum annual levels should be well within the IAEA 20 mSv guideline for trained workers, with a current maximum estimate equal to 2.6 mSv/year.

The IAEA contemplates regulation of sites such as Russeifah, Area 3 in the Safety Guides on Occupational Radiation Protection (IAEA 1999) and Occupational Radiation Protection in the Mining and Processing of Raw Materials (IAEA 2002). The IAEA "Occupational Radiation Protection" (IAEA 1999) states:

> *"2.24…[T]he BSS [Basic Safety Standards] provides for the regulatory authority to specify other situations involving exposure to natural sources of radiation to be subject to the requirements for practices. The other situations in which exposures to natural sources of radiation at work may need to be considered include:*
>
> > *"(a) the mining, milling, handling and use of materials containing elevated levels of natural radionuclides (in addition to those ores from which uranium and thorium are extracted);*
> >
> > *"(b) the presence of materials in which the activity concentration of natural radionuclides has been increased during processing, for example, in the deposits or scale sometimes found in the pipe work of oil rigs;"*
>
> *"2.25. The regulatory authority should first undertake an investigation of these situations to determine the extent of the exposures. Where the exposures are considered sufficient to warrant attention, the regulatory authority should decide whether they should be subject to the requirements for practices.*
>
> *"2.27. In the situations described in parts (a) and (b) of para. 2.24, the handling and use of bulk quantities of minerals and other materials containing natural radioactive substances with activity concentrations in the range 1–10 Bq/g (of the parent radionuclide) could, under dusty conditions, result in an annual effective dose of about 1–2 mSv. Experimental data on the exposure of workers to gamma radiation and dusts from the surface mining and milling of sedimentary phosphate ores containing about 1.5 Bq/g of uranium-238 support this assessment. Control, if considered necessary, would include the use of methods to suppress or contain any airborne dusts and general radiological supervision."*

This guidance has recently been updated by IAEA (IAEA 2014), The latest BSS document now contains more detailed requirements for regulatory oversight, but the above set of statements were the guiding principles for the current, as well as the May 2013 study report, included as Appendix B1.

Thus the IAEA's latest edition of its BSS (No. 3 GSR, IAEA 2014) provides the limits for public doses which should be applied when designing dose reduction actions at Russeifah Area 3. Therefore, in accordance with this BSS, under normal circumstances the only effective dose limits for public exposures is 1 mSv/year. (A 0.5 mSv/year supplemental recommendation sometimes quoted by other agencies for children and sensitive populations is not discussed in the BSS. Given that the dose models used in the Area 3 evaluation contain conservative assumptions, only the 1 mSv/year effective dose limit from the BSS is considered here for evaluating remedial strategies.

In addition, guidance for radon exposure for facilities under the jurisdiction of the United States Environmental Protection Agency (USEPA) is provided in "Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites" (USEPA 2002), which states: *"…exposures to radon in workplaces should be subject to the requirements for occupational exposure if the radon concentration exceeds the action level…"* Although radon emanation samples were evaluated for this study, neither they nor the present modeling are appropriate to predict radon concentrations in structures and caves. Radon concentrations in structures vary greatly depending upon the underlying geology, the structure, weather conditions, and local ventilation, among other factors.

Table 9 presents a summary of the results obtained from the radiological assessment of existing site conditions. Results highlighted in bold exceed IAEA recommended dose limits; warranting remedial action.

Table 9. Comparison of dose modeling results to applicable IAEA dose limits

Scenario	Applicable IAEA Recommended Dose Limit	Existing Conditions
Off-site Resident	1 mSv/year (adult)	**5.95 mSv/year**
Park Visitor	0.5 mSv/year (children)	0.06 mSv/year
Outdoor Worker	20 mSv/year (trained worker)	0.94 mSv/year; max. 5.45 mSv/year
Farm Market	1 mSv/year (adults) 0.5 mSv/year (children)	0.96 mSv/year

3.3.3 Recommendations and Conclusion

Final results indicate that the average uranium concentration of the ore material found at the Russeifah Area 3 site is greater than the IAEA recommended criteria for exemption from regulatory controls. The dose assessments conducted for exposure scenarios of likely receptors indicate the possibility that workers and members of the public could receive doses up to 6 mSv/year (not including contributions from radon). With the exception of exposures estimated for the nearest residential locations, none of the risk levels predicted for each receptor group would be considered to be extraordinarily high for the situations represented, but some are high enough to warrant continued review and potential improvement.

Assessment of individual facilities is required to evaluate the radon exposure to workers and residents. Such exposures to workers in facilities at Russeifah Area 3 are subject to the requirement of protective practices according to IAEA standards.

The assumptions used in this initial site survey measurement and preliminary risk assessment study are intentionally conservative. Future users of the site should compare actual planned site operations to the scenarios modeled in this report to gauge relative predicted dose. In addition, the complementary air modeling performed to help interpret how typical the measured results might be, compared with other days and wind conditions led to further prediction of long-term estimates of total exposures to nearby public areas, as well as on-site work areas.

The modeling results, alongside predicted concentrations and the residential exposure dose pattern, suggest that several local subareas may experience concentrations that are significantly higher than those measured either directly or through analysis of samples acquired in the preliminary field testing and soil radiation measurement phases of the assessment study. Future long-term monitoring of fugitive dust concentrations in the site vicinity, coupled with erosion management plans, can be used to further define and limit these potential areas of long-term impact.

According to IAEA Safety Guides, both public and worker radiation exposures at Russeifah Area 3 would likely be subjected to the requirements of protective practices. This is due to the potential dose resultant from worker and public exposures to airborne dusts and radon originating from the ore material that comprise the site.

Based on the survey and sampling results from Russeifah Area 3, any development on the site must take into account radiation safety measures to protect future site users from prolonged exposure risks. The data analyses and the comparative modeling of the potential addition of inhalation exposures are sufficient to conclude that the associated risks should not be dismissed, under IAEA standards, without further consideration by the responsible regulatory body.

The measured outdoor levels of radon were observed to be comparable to those identified as general USEPA and USNRC regulatory requirements for uranium-contaminated tailings materials at mining or milling sites. As outlined in the USNRC's Regulatory Guide 3.64, both of these agencies have cooperatively adopted the historical USEPA 10CFR 192 requirement (USEPA, n.d. …Standards for Uranium…).: *"that a cover be designed to produce reasonable assurance that the radon-222 release rate would not exceed 20 pCi/ m^{2-}s (= 0.74 Bq/m2-s) for a period of 1000 years to the extent reasonably achievable, and in any case for at least 200 years when averaged over the disposal area over at least a one-year period."* (USNRC 1978; USEPA 2000). However, this US guidance only serves as a point of reference, as it is specifically not legally applicable to the Russeifah site. Further, the related dose contribution for radon present in indoor workplaces has not been considered in detail in the present study, because none of the data acquired was directed toward assessing indoor air levels. Therefore this source of additional exposure may need to be considered further in the future, for both on-site workers and residents near site boundaries.

The exact radiation protection practices that are required will be specified by the governing regulatory authority, the Jordan Nuclear Regulatory Commission (JNRC). The owner(s) of any facilities operating at this site in the future should consider this measurement survey and dust modeling predictions and appropriately notify the JNRC of plans for future site activities to confirm applicable administrative controls or requirements are successfully met.

4 DESIGN

4.1 Site Issues and Design Objectives

The site topographic survey, field geotechnical investigation and slope stability analysis, in addition to a radiation study identified the following site issues to be addressed by the remedial design:

- Radiation exposure to site users
- Radiation exposure to nearby residences through inhalation of radioactive fugitive dusts
- Questionable physical stability of the pile due to steep and unstable side slopes
- The random nature of the site topography; which makes the area unsuitable for development

In an attempt to tackle the aforementioned issues, the design objectives were set to encompass the following:

- Stabilize the slope of the pile and ensure stability in both static and dynamic conditions
- Cover the pile material such that the risk of radiation exposure and dust migration to the immediate vicinity is reduced

4.2 Remedial Design Strategy

The remediation strategy focuses on reducing the risk of dust inhalation and direct exposure to radiation, while ensuring the geotechnical stability and radiological safety of the site for future development. As such, the following design components were considered based on the results of the field investigations and studies presented in section 3 of this document:

- Pile reshaping and slope stabilization
- Engineered covers for flat faces and side slopes as protection from TENORM
- Storm water management and drainage

The remediation strategy would involve grading the side slopes of the main stockpile to 3H:1V and the addition of a grouted riprap cover for slope stabilization and to eliminate the risk of fugitive dust inhalation. The top of the pile would then be flattened and covered with one of two engineered covers designed to serve as a radiological buffer and a foundation for both hardscape and landscape development activities. Terraces of 3 meter width would be created at every 10 meters of elevation and, like the top face of the flattened pile, be covered with the same materials to achieve radiological protection.

Side ditches and chutes would be integrated into the side slope cover with the purpose of effectively managing storm water and surface runoff. The storm water management component of the remedial design is of critical importance to protect the engineered cover from erosive forces and ensure performance integrity over time.

A modeling exercise was carried out in order to test the long-term effectiveness of the proposed remedial design (with respect to radiation protection). The results of this exercise have been summarized in section 4.3.2.3 (the complete report can be found in Appendix B2).

4.3 Phosphate Pile (Area 3) Remedial Design Components

4.3.1 Slope Stability

As evident from the results of the topographic survey and geotechnical investigation (section 3.1), the side slopes of the phosphate pile are irregular and highly unstable. As such, the current state of the pile makes it unsuitable for development and calls for re-grading as the first step of the site's remediation and rehabilitation. Section I: Criterion 4 of Appendix A of 10 CFR Part 40[3], The United States Nuclear Regulatory Commission states:

> *"(c) … In general, slopes should not be steeper than about 5H:1V. Where steeper slopes are proposed, reasons why a slope less steep than 5H:1V would be impracticable should be provided, and compensating factors and conditions which make such slopes acceptable should be identified."*

However, it is worth noting that this is not directly applicable to Area 3; and that detailed geotechnical investigations and modeling exercises were already carried out assuring the long-term stability of the pile with slopes graded to 2.25H:1V or milder. Furthermore, the addition of grouted riprap as a cover material for the side slopes (and the required addition of terraces and further grading) contributes significantly to enhancements in the stability of the stockpile. The use of riprap for slope stabilization of fine textured, non-cohesive soil slopes is common practice (Maine Department of Environmental Protection: Bureau of Land and Water Quality 2003) and can also be deemed effective in the context of Russeifah Area 3 due to the physical and textural similarities between the pile contents and the soil types in typical riprap applications (see section 4.3.2.2).

Additionally, the presence of a road very near to the eastern side of the pile requires that side slopes exceed 3H: 1V – necessitating the use of geo-grid along the path of the road.

4.3.1.1 Earthwork: Cut and Fill, Re-grading, and Compaction

The original grading of the stockpile and surrounding areas is greatly irregular and in several cases, highly unstable. The original contours of the site are shown in Drawings 1, 2 and 8 as presented in Appendix E of this document. Ultimately, if the site is to be suitable for development, varying degrees of earthwork would be required in different parts of the site. As such, Area 3 was divided into three distinct zones with unique characteristics (as outlined in section 3.3.1); each zone would be subject to its own earthwork requirements.

The overall approach to rehabilitate the site necessitated reshaping the pile such that the maximum possible area of flattened land can be recovered for development activities, and to facilitate drainage control throughout the site. Reshaping involved cut and fill processes, which entail 'cutting' isolated piles (i.e. the fine aggregate pile and the 'loose' branch of the main stockpile), and filling any pits around the site with the material, and finally 'mounding' the main pile with any surplus materials.

In order to prepare the site for capping (with either of the protective covers or grouted riprap), the site will need to be re-graded and compacted to ensure geotechnical stability (i.e. preventing differential settlement), controlled storm water drainage and sustained access road construction. A summary of required earthwork for each zone designation is presented in Table 8, and proposed final grades are presented in Drawings 2-6 (Appendix E).

---

[3] Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material From Ores Processed Primarily for Their Source Material Content (USNRC n.d.)

Table 10. Required Earthwork for the Park, Fine Aggregate and Stockpile Zones

Zone	Required Earthwork
Park Area	Flattened and graded to a 0.5% incline to facilitate runoff and reduce ponding.
Fine Aggregate Processing Area	All fines will be removed and pushed towards the main stockpile. Once removed, the fines area will be graded to a 0.5%incline (matching the park area) to facilitate runoff and drainage.
Main Stockpile	The pile will be graded at an incline to facilitate runoff and reduce ponding. The top face of the pile is to be graded to varying levels (as shown in Drawings 4 & 5) to accommodate for a proposed ramp and promote effective drainage control. Side slopes will be graded to a 3H:1V slope; with 3-m wide terraces at every 10 meters of elevation. Terraces will be inclined at 1% (across) and laterally inclined at 0.5% to facilitate drainage into the chutes (storm water management system components are presented in section 4.3.3)

4.3.1.2 Geo-grid

The proximity of a road along the East-Northeastern face of the stockpile restricts the ability to meet the necessary grading requirements outlined in section 4.3.1.1. This necessitates the use of geo-grid to achieve slope stability prior to the application of the grouted riprap layer. Geo-grid specifications are to be selected such that slopes steeper than the working gradient throughout the remainder of the site can be supported. Geo-grid fill materials are to be obtained from a radiation-free source.

4.3.1.3 Grouted Riprap (Slope Stabilization Context)

The use of riprap is expected to prevent radioactive dust emissions currently influencing nearby residences when applied to the side slopes of the main stockpile (see section 4.3.2.2). Furthermore, the proximity of squatter communities to unstable side slopes in the Western part of Area 3 was identified as an area of concern during the design process. Squatter houses are not typically built according to national specifications and lack the required structural stability to withstand external forces. Little space is available between residences and the side slopes to allow for earthwork in this part of the site, and this necessitated the installation of some form of barrier to protect the squatter communities on and near the site; grouted riprap was selected for this purpose.

As shown in Drawing 7 (in Appendix E), a 30 cm grouted riprap layer is to cover the side slopes of the main stockpile and the slopes immediately adjacent to existing residences. The riprap layer will be supported by stubs at 10 m intervals and at the ends of protection. Section A-A (shown in Drawing 7, Appendix E) presents a cross sectional view of the designed stubs and their dimensions. It is worth noting that the gradation of stones to be used in the grouted riprap shall meet the specifications set forth by the Jordanian Ministry of Public Works and Housing for the construction of roads and bridges.

4.3.1.4 Ramp and Fencing

A proposed ramp has been included in the remedial engineering drawings for the Russeifah Area 3 site with the aim of easing vehicular access to the top face of the main stockpile. Located at the northwestern-most face of the main stockpile, the proposed ramp will be inclined at 14.27% (as shown in Drawing 6). As shown in Detail A (Drawing 7), the 6 m-wide ramp will consist of a 5 cm-thick layer of bituminous concrete wearing course atop a 20 cm base course layer. Drawing 7 (Appendix E) also presents ramp section views in both cut and fill.

In addition to the ramp, a 1.25 m fence was added to the perimeter of the top face of the capped stockpile to provide preliminary, non-obtrusive protection to site visitors. Fencing details are presented in Drawing 7A.

4.3.2 Radiation and Dust Control

The RA submitted in May 2013 (Appendix B1, Parts 1 and 2) concluded that the average concentrations of U^{238} in the ore are high enough to warrant regulatory controls based on criteria established by the IAEA (> 1000 Bq/kg) (IAEA 2004).

The RA indicated that the greatest radiological hazard results from the suspension of airborne particulates (and to a lesser extent, direct exposure and radon emanation resulting from the uranium decay chain). The air modeling results summarized in Appendix B1, suggest the several local sub-areas may be exposed to radiation doses higher than the IAEA recommended long-term exposure doses (IAEA 1996). Therefore, dust control at the pile site is deemed essential to protect nearby residents.

As noted in Section 3.3.3, another notable radiological component of Russeifah Area 3 is the release of radon gas. Radon is a naturally-occurring radioactive gas associated with the uranium decay chain (USEPA 2013). Furthermore, radon is known to be a heavy gas and subsequently tends to accumulate in low-lying areas. Despite the fact that the majority of the measured radon emanation rates at various locations at the Area 3 site, and all of the averages for the identified subareas were below[4] USEPA recommended guidelines for remediation planning (0.74 Bq/m^2-s), that agency states that even the slightest exposure to radon is associated with damage to sensitive lung tissue and an increased risk of cancer (USEPA 2013).

With that in mind, the radiological component of the remedial design (schematically summarized in Figure 7) focused on:

- preventing the suspension of dust particles (brought about by erosion);
- attenuating the release of radon gas;
- providing sufficient shielding from direct exposure to gamma radiation; and
- developing post-remedial site development recommendations aimed at minimizing prolonged direct exposure and sustaining the effectiveness of the engineered design.

[4] 1) Fines piles: 0.283 ± 0.023 Bq/m^2-s; 2) Compacted ore: 0.223 ± 0.013 Bq/m^2-s; 3) Stockpiled ore: 0.594 ± 0.093 Bq/m^2-s.

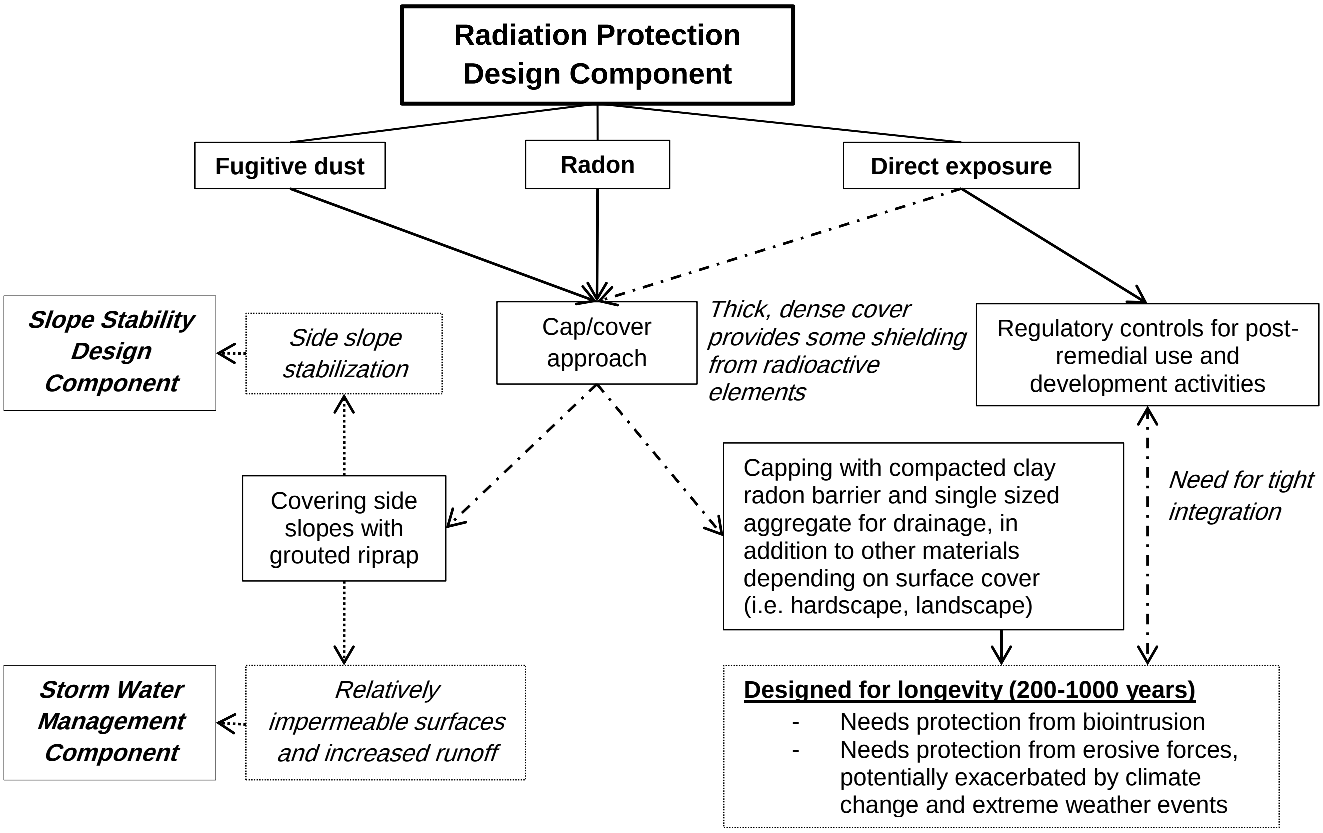

Figure 7. System design approach addressing radiological components of Russeifah Area 3

4.3.2.1 Basis of Cover Design

To date, the JNRC has not yet developed specific criteria for the management and containment of wastes that are radioactive in nature. However, it has adopted the recommendations and guidelines issued by the IAEA and the United States Nuclear Regulatory Commission (USNRC 2014).

Covers have been described as "*the component controlling the release of contaminants from hazardous and radiological waste-disposal facilities to the environment"* (Smith & Weston 1999). The USNRC dictates the need for long-term containment of low-level radiologic waste (in the order of 200-1,000 years)[5] (USNRC 1978). The cap/cover method is a very-well documented and regulated[6] tactic to effectively manage radioactive waste – particularly when it comes to uranium mill tailings. Saling and Fentiman (2001) have studied various forms of radioactive waste disposal sites – highlighting the fact that despite general acceptance of the overall approach, the technical detailing of cap and cover designs is heavily influenced by local contexts and climatic conditions. The nature of the radiological issues presented in Russeifah Area 3 was deemed similar to those that arise with uranium mill tailings with varying degrees of exposure and impact intensity. Therefore, the cover designs proposed for the phosphate stockpile adopted the typical approach to the disposal of uranium mill tailings, with some tailoring to suit the local climate, urban context, and observed (measured) radiological conditions.

[5] Section I: Criterion 6.1 of Appendix A of 10 CFR Part 40 and USNRC Regulatory Guide 3.64 (USNRC 1978).
[6] The United States Congress passed the UMTRCA in 1978; authorizing the USDOE to stabilize, dispose of, control and provide long-term care for disposal sites containing uranium mill tailings and other contaminated material; the EPA to develop standards and mandate remedial action; and the USNRC to license disposal facilities. (Smith & Weston 1999)

Disposal cell cover designs for uranium mill tailings are typically based on designs developed by the United States Department of Energy's (USDOE) Uranium Mill Tailings Remedial Action (UMTRA) Project office. However, it is worth noting that no 'standard' UMTRA disposal cell design exists due to the fact that the effectiveness of a cover is contingent upon site-specific parameters and the context of application (Lommler, Chen, Artiglia, Guros, Bridgeman, & Cox 1999).

A "checklist" cover was developed in 1989 to provide design guidance following the identification of potential problems associated with earlier cover designs (Smith & Weston 1999). This marked one of the earliest attempts of UMTRA disposal cell cover design standardization – despite the fact that individual components could still be selected on a site-specific basis. The main issues to be considered in cover design (as identified by the checklist) are as follows:

- Control erosion of tailings by wind or runoff
- Limit infiltration
- Provide freeze-thaw protection
- Inhibit radon emanation
- Drain precipitation
- Control biointrusion
- Self-renewal and adaptability of vegetation to climate change

However, not all of these considerations are applicable in the context of Russeifah Area 3. Nonetheless, it is crucial that cover designs are able to provide long-term encapsulation of waste mill tailings serving three purposes:

- Minimization or prevention of storm water infiltration,
- Control the escape of toxic gasses (such as radon), and
- Provide dust control by minimizing erosion

Furthermore, covers designed for long-term containment are typically based on a passive design philosophy; such that minimal maintenance is required due to the integration of dynamic ecosystem components and processes (e.g. vegetative covers promoting evapotranspiration as a form of storm water management) (Smith & Weston 1999).

Since the launch of the UMTRA Project in 1978, over 20 remedial covers were designed - 19 of which were constructed by 1999. Cover materials and thicknesses of all constructed disposal sites are summarized and presented in Table 9. The site-specific conditions that have influenced each of the 19 designs were considered such that a 'base design' - i.e. a single functional layer providing all required radiological protection - for Area 3 could be selected and tested for long-term effectiveness and sustainability (See Section 4.3.2.4 – Modeling for Remediation Planning). The base design will then be supplemented with layers of functional earthen and geosynthetic materials to ensure protection from climatic forces and biointrusion in line with envisioned development plans for the site. Base design parameters are presented and explained in sections 4.3.2.2 and 4.3.2.3.

Table 11. Cover Materials and Specifications of Constructed UMTRA Disposal Facilities

Site	Radon Barrier Material (thickness)	Freeze/Thaw Barrier Material (thickness)	Bedding Layer (thickness)	Erosion Protection, Rock or Vegetation (thickness)	Special Layers, Capillary Break, Biointrusion, etc.
Ambrosia Lake, NM	Clay (2.5’)	Incorporated in radon barrier	(0.5’)	Top: Riprap (0.5’) Sides: Riprap (1.0’)	None
Burrell, PA	Clay (3.0’)	None	(1.0’)	Rock (1.0’)	None
Canonsburg, PA	Layer A: Clay (2.0’) Layer B: Bentonite amended (1.0’)	None	(0.75’)	Select growth media soil (1.0’); over Top: Riprap (1.0’) Sides: Riprap (2.0’)	None
Durango, CO	Top: Clay/silt (2.0’); no bentonite amendment and geotextile bentonite layer Sides: (2.0’); upper 1.5’ bentonite amended	Top: (2.5’) Sides: (1.5’)	(0.5’)	Top: Vegetated Sides: Riprap (1.0’)	Capillary break and biointrusion barrier layer (1.5’)
Falls City, TX	Clay (3.0’)	Layer A: Topsoil (0.5’) Layer B: Silty clay growth media (2.5’)	Top: None Sides: (0.5’)	Top: Vegetated Sides: Riprap (1.3’)	None
Grand Junction, CO	Clay (2.0’)	Top (2.0’)	(0.5’)	Riprap (1.0’)	None
Green River, UT	Clay (3.0’)	None	(0.5’)	Riprap (1.0’)	None
Gunnison, CO	Bentonite amended (1.5’)	(6.0’)	(0.5’)	Top: Riprap (0.5’) Sides: Riprap (1.0’)	Capillary break (0.5’)
Lakeview, OR	Clay (1.5’)	None	(0.5’)	Top: Rock-soil matrix (1.0’) Sides: Riprap (1.0’)	None
Lowman, ID	Clay (1.5’)	None	(0.5’)	Riprap (1.0’)	None
Maybell, CO	Bentonite amended (1.5’)	(4.0’)	(0.5’)	Top: Riprap (1.0’) Sides: Riprap (1.0’)	None
Mexican Hat, UT Monument Valley, AZ	Bentonite amended (2.0’)	None	(0.5’)	Top: Riprap (0.67’) Sides: Riprap (1.0’)	None
Naturita, CO	Clay (3.0’)	(5.5’)	(0.5’)	Riprap (1.0’)	None
Rifle, CO	Clay/silt* (1.5’); upper 1.0’ bentonite amended	(6.8’-18.6’)	(0.5’)	Riprap (1.0’)	Filter layer between radon barrier & freeze barrier (0.5’)
Shiprock, NM	Clay (6.4’)	None	(0.5’)	Riprap (1.0’)	None
Salt Lake City, UT	Clay (7.0’)	None	(0.5’)	Riprap (1.5’)	None
Slickrock, CO	Clay (1.5’)	(2.0’)	(0.5’)	Top: Riprap (0.67’) Sides: Riprap (1.0’)	None
Spook, WY	Clay (1.5’)	N/A	N/A	N/A	(10.0’)
Tuba City, AZ	Bentonite amended (3.5’)	None	(0.5’)	Top: Riprap (0.5’) Sides: Riprap (1.0’)	None

Reference: Lommler, Chen, Artiglia, Guros, Bridgeman, & Cox 1999

*Smith & Weston 1999

4.3.2.2 Top: Protective Soil Cover (Base Design)

It is worth reiterating that UMTRA cover designs, in addition to being site-specific, have evolved over time to consider a wider range of environmental concerns. This evolution was not only driven by the need to ensure the containment of tailings (i.e. preventing the re-suspension of airborne dusts), but also gain confidence in long-term performance.

The base design of the proposed cover is intended to address issues associated with the radiological nature of the ore material of Russeifah Area 3 by:

- Preventing the re-suspension and dispersion of fugitive dusts to the surrounding environment
- Providing sufficient radiological shielding to nearby communities and future site users
- Attenuating the release of radon gas
- Limiting infiltration into the stockpile

Compacted clay is typically used for the construction of barrier layers due to its low hydraulic conductivity (i.e. permeability) which severely restricts the infiltration of storm water into tailings piles while also providing additional shielding from direct gamma radiation exposure (Smith & Weston 1999). Furthermore, clay has a geological service life and durability that well-exceeds regulatory design criteria, indicating hardly any active maintenance requirements (Smith & Weston 1999); the culmination of these two properties makes the use of clay a much more favorable option for use in the base design of the remedial cover (as opposed to geosynthetic textile materials).

In light of this conclusion, the main issue associated with the Area 3 base design was determining the requisite thickness of the compacted clay layer such that the maximum possible radon attenuation and shielding from gamma radiation could be achieved without significantly over-designing the barrier and incurring unnecessary costs. As such, a relatively conservative approach was adopted and a 0.7-meter–thick (~2.3') layer of compacted clay was selected for use in Area 3. The selected thickness falls within the middle range of thicknesses used for the disposal of uranium mill tailings (shown in Table 9). Despite high degrees of confidence in the selected barrier thickness, additional modeling was performed in order to verify the degree of effectiveness in the context of Area 3. The results of the RESRAD and air dispersion models are summarized in Section 4.3.2.4 of this document, and presented in full in Appendix B1.

Furthermore, the required service-life of UMTRA cover designs leaves important components (mainly the radon barrier) particularly vulnerable to degradation by climatic and ecological forces (i.e. biointrusion, freeze/thaw, and extreme runoff). This necessitated the integration of some protective layers into the base design to safeguard the performance integrity of the cover - regardless of the future use.

There was enough reason to believe that the 0.7-meter compacted clay layer would be able to withstand degradation due to freezing and/or thawing triggered by freak winter events in Russeifah over the course of the cover's service life. This working assumption was based on an understanding of local climatic conditions, and was justified by a comparison of climates between Russeifah and other UMTRA project sites with comparable thicknesses (i.e. Ambrosia Lake, NM; Lakeview, OR). Hence, the addition of a freeze/thaw protection layer of soil materials for was deemed unnecessary for the base design of the remedial cover.

Ensuring effective drainage was deemed an integral component of the cover design. Failure to do so facilitates the retention of moisture and ponding near the clay layer due to the low hydraulic conductivity. The accumulation of water enables plant germination and subsequently the penetration of the clay layer by roots – compromising the performance integrity of the cover. Furthermore, the absence of some form of drainage layer could make the clay vulnerable to the erosive forces of storm water runoff on the top face of the covered pile. A 0.3-meter (1.0') drainage and biobarrier layer has been proposed to serve as a buffer; shielding the clay layer from the surrounding biosphere. The dual-use layer is to be composed of a single-sized aggregate (i.e. gravel and/or coarse sand) to promote drainage and resist the erosion of the radon barrier; this would significantly reduce moisture retention and subsequently prevent plant growth undesirably close to the clay layer. Lastly, the biobarrier/drainage layer is to be capped with one of the two final cover designs presented in Drawing 7 – depending on the envisioned post-remedial development plans. Narratives pertaining to the development of the hardscape and landscape cover designs are presented in Section 4.3.2.5.

4.3.2.3 Side Slopes: Grouted Riprap (Radiological Context)

The addition of riprap layers along the side slopes of pile covers is common practice according to the UMTRA design specifications presented in Table 9. This practice is to counteract the tendency for the aerodynamic roughness of tailing materials to enhance the re-suspension of dust during wind erosion events. Therefore, the side slopes of the stockpile are to be covered with a 0.3-meter thick layer of grouted riprap, aimed at resisting wind erosion and dust re-suspension - while simultaneously adding additional shielding from direct exposure. It is of pivotal importance that the stone selected for the riprap cover is able to withstand weathering by the elements during designed service life, and be chemically stable enough to serve the riprap's twofold purpose. No studies were conducted pertaining to the radiological shielding properties of the proposed riprap materials however shielding effectiveness is based on the average density of the cover material accounting for the density of the shielding material and void spaces. However, research indicates that limestone (which is typical of the area) is extremely effective in radiological shielding (Konno 1987). As such, the riprap layer will have properties consistent with those outlined in Jordanian specifications – lending enough confidence in all elements of the remedial design.

4.3.2.4 Modeling for Remediation Planning

A modeling exercise was undertaken to support the remedial design for Russeifah Area 3. The updated study built upon the results of the radiological assessment of existing conditions as measured in May 2013. The current study sought to identify how the newly identified cover plan would amend the previous source assignment for the airborne dust modeling. The previous analysis (see Appendix B1) showed that the inhalation of airborne dust containing trace radioactivity was potentially the most important contribution to total annual radiological dose. Instead of using a single source strength for all areas of the site (as in the previous study) the updated air modeling now considered the much lower radiological content of the proposed "clean" earthen cover materials for many of the specified sub-areas of the site (see Table 12, Figure 8).

Table 12. Subarea Designation Criteria and Corresponding Modeling Assumptions

Sub-area(s)	Characteristic Elements under Remedial Design	Modeling Assumptions[7]
A	Flattened, top face of the stockpile; to be covered with protective soil cover presented in section 4.3.2.1	Effective surface ^{238}U content of **125.5 Bq/Kg,** based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area.
B	Graded side slopes; to be covered with grouted riprap	No data pertaining to the background radioactivity of riprap materials was available at the time of the modeling exercise. Therefore the effective surface ^{238}U content of **125.5 Bq/Kg** was selected based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area. This is assumption is very conservative, bearing in mind that radioactivity levels in limestone (which is the assumed riprap material) are usually much lower than the selected value.
C, D	Fines, to be graded and pushed towards main pile prior to covering; residual matter is assumed to be natural soil, will be covered with the protective soil cover (or a slightly modified version to meet surface structural conformation requirements)	Effective surface ^{238}U content of **125.5 Bq/Kg,** based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area.
F	Planned location for the Ministry of Environment's Eco Park, surface composed of compacted ore; To be covered with the protective soil cover (or a slightly modified version to meet surface structural conformation requirements)	Effective surface ^{238}U content of **125.5 Bq/Kg,** based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area.
G	Represents the small, eroded area of exposed phosphate within an existing soccer field.	Worn areas would be covered with clean top soil similar to that used for the rest of the proposed cover above, and thus it will also have a surface activity of **125.5 Bq/Kg.**
U1	Witnessed the construction of a police building during the study period; might be covered with the protective soil cover (or a slightly modified version to meet surface structural conformation requirements)	Effective surface ^{238}U content of **125.5 Bq/Kg,** based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area.
U2	Old Russeifah Mine area; not within intervention boundaries	Will remain exposed; assumed to have surface soils similar to "background" concentrations of natural radioactivity (as measured in initial study)
U3	Ore material, will be covered with grouted riprap	No data pertaining to the background radioactivity of riprap materials was available at the time of the modeling exercise. Therefore the effective surface ^{238}U content of **125.5 Bq/Kg** was selected based upon lab measurements of "dark soil" previously used as a partial cover material in part of the existing Park area. This is assumption is very conservative, bearing in mind that radioactivity levels in limestone (which is the assumed riprap material) are usually much lower than the selected value.
U4	Geological limestone deposits (part of natural underlying geology); and witnessed the construction of a fiber-glass factory during the study period. Will remain exposed.	No significant contributions to radioactivity levels on the site (above background levels). Assumed effective surface ^{238}U content of **317 Bq/kg,** based on the background area lab data and the fact that their previous land use is not known to involve TENORM storage at edges of the Area 3 site.

[7] Use of ^{238}U as the primary radionuclide component representing the set of NORM progeny, expected to be in secular equillibrium, based on laboratory measurements, is explained in Section 2.1 above and elaborated in the calculations for ingestion and inhalation exposure doses detailed in Appendix B2 Tables 10 and 11.

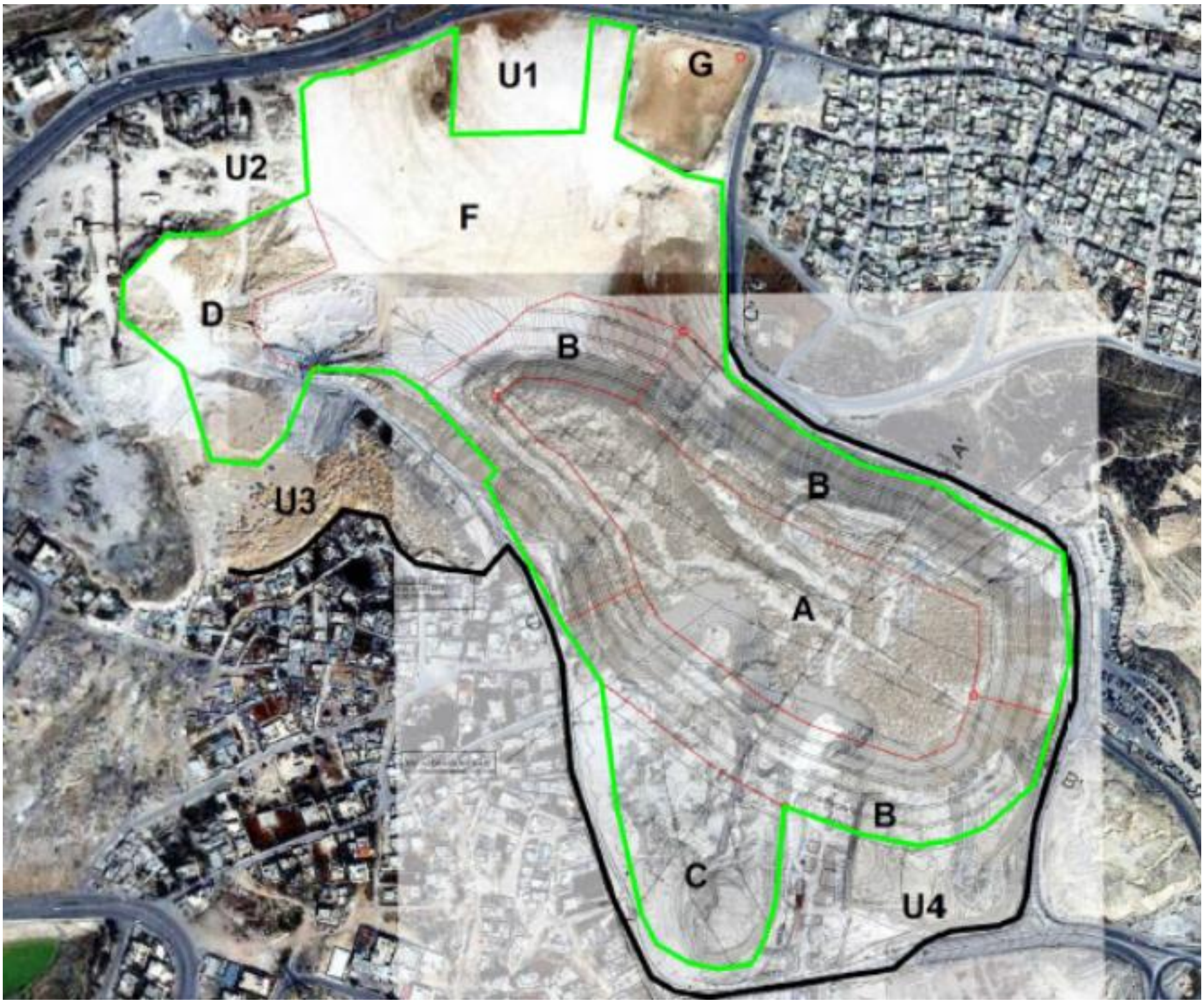

Figure 8. Sub-Area Designations within Study Area Limits

The radiological study to analyze the benefits and effectiveness of the proposed remediation plan consisted of the following:

- **Dose Modeling Remediation Cover Effectiveness Analysis:** A supplemental analysis of the effectiveness of the proposed cover design as a means to control radon and gamma radiation from underlying TENORM using the RESidual RADioactive (RESRAD) model (USDOE 2009) to demonstrate the importance of erosion control as a dominant factor for longevity of cover effectiveness. This involved running sensitivity tests for a range of erosion rates (between 1-10 mm/year) to evaluate how many years it would take before the cover layer was totally degraded by climatic forces.
- **Air Modeling for Remediation Planning:** An updated AERMOD (USEPA 1995) modeling exercise was used to identify post-remedial radiological dust emission source strengths for specified sub-areas in line with anticipated remedial interventions.
- **Radiological Dose Prediction for Remediation Cover Plan:** Radiological dose calculations needed to be updated to relate more specifically to the remediation cover plan in light of the results of the RESRAD and AERMOD analyses.
- **Graphical Summaries of Air and Radiological Modeling Results**

RESRAD Remediation Cover Effectiveness Analysis

In order to assess the effectiveness of the selected thickness of the compacted clay layer, further modeling was needed to gauge any residual post-remedial radioactive materials in and around Area 3. Developing an accurate assessment required an additional run of the air dispersion models used in the radiological assessment (for consistency) in addition to a risk assessment model, based on the notion that the clay layer alone would provide the needed protection.

For our purposes, RESRAD model was the top ranking among other similarly purposed dosimetric models. RESRAD 6.5 is a computer model developed by the Argonne National Laboratory to estimate radiation doses and risks from residual radioactive materials (USDOE 2009). The basic model has been widely used by the USDOE, USEPA, the U.S. Army Corps of Engineers, and the USNRC (in addition to industrial firms, universities and foreign government agencies and institutions) since 1989. The model evaluates the radiological dose and excess cancer risk to an individual with prolonged exposure to an area where soil is contaminated with radionuclides (i.e. workers and residents). The RESRAD model is able to consider radiological contamination in a variety of settings, including contaminated sites covered with a 'radiologically clean' layer – which would represent the post-remedial case in Area 3 (S. Cohen & Associates 2010).

Nine exposure pathways are taken into account by the RESRAD model, including direct exposure from contamination in soil, inhalation of particulates and radon and incidental ingestion of soil, among others that are not directly applicable to Area 3. In order to obtain representative modeling results, the site was broken down into several subareas as previously outlined, and graphically presented in Appendix B2, Figure 3.

Predicted future direct exposure levels at the surface were evaluated using the RESRAD model for a range of periods after introduction of the proposed remediation cover materials. When the new cover is in place, the dose to the hypothetical receptors at the surface, due to underlying TENORM (ore/tailings materials), is effectively reduced to near zero ($< 1 \times 10^{-6}$ mSv/year), with only the natural radionuclide concentrations present in the cover material contributing the residual dose rate at the surface.

The current update analysis utilized the proposed cover material specifications available from the Area 3 geotechnical studies to evaluate the effectiveness of the proposed cover in reducing radiation levels at the surface, as well as to compare the surface dose rates for a couple of alternative cover designs. The cover thicknesses evaluated with RESRAD ranged from 130 cm to as little as 15 cm. The anticipated range for local erosion rates were all above the model default rate of one millimeter per year (mm/year) (for clay with slopes < 2%). The rates assumed for the Area 3 site ranged from 2.5 mm/year appropriate for slopes less than 6%, to 10 mm/year for slopes ~15%, to 33 mm/year for more extreme slopes and higher wind domains.

In an erosion environment that might be assumed for the present design (2.5 mm/year, e.g., for slopes less than 6%), the expected durability of a cover as thick as 130 cm should provide a long period of relief. However, the results shown also indicate that if the rate of removal is larger than estimated in that case, more frequent maintenance or replacement would be required to continue the desired degree of radiation exposure control. The initial dose rates at the surface for a 1.3 m cover for the first 100 years of its presence range slowly upward from 1×10^{-9} with a 1 mm/year erosion rate. At 300 years, surface dose rate increased to about 5×10^{-7}

mSv/year. By 1000 years, when the cover had entirely eroded away, the annual dose rate increased to 4.8 x 10^{-2} mSv/year revealing the complete failure of containment by that time.

When the erosion rate assumption was increased to 10 mm/year, which might be more typical of an arid windblown surface with sparse vegetation, the cover has completely eroded away at about 130 years, with the surface dose rate reaching an equilibrium rate of 4.8 x 10^{-2} mSv/year, (48 uSv/year), but this modeled ^{238}U and decay progeny contribution is still a fraction of the10 to 40 uSv/hour reported from the walkover total gamma radiation measurements reported in the previous assessment. Early results made it clear that it did not take the entire 130 cm (with 70 cm of clay) to reduce the dose rates at the surface to extremely low levels (neglecting the contributions from radon, which were extremely low compared with the direct gamma radiation). Table 13 presents a summary of total radiological doses and cover failure times based on the RESRAD analysis.

Table 13. Summary of Total Radiological Doses and Cover “Failure” Times

Remediation Cover Depth	130 cm	130 cm	130 cm	70 cm	30 cm	15 cm
Erosion Rate *(mm/year)*	*2.5*	*10*	*33*	*2.5*	*2.5*	*2.5*
Surface Dose (intact) (mSv/year)	<4 x10^{-08}	<4 x10^{-08}	<4 x10^{-08}	<4 x10^{-08}	<4 x10^{-08}	<4 x10^{-08}
Surface Dose (> failure) (mSv/year)	4.8 x10^{-02}	4.8 x10^{-02}	4.8 x10^{-02}	4.8 x10^{-02}	4.8 x10^{-02}	4.8 x10^{-02}
Time to Failure (years)	520	390	39.5	280	120	60

These RESRAD results led to the conclusion that the main issue for remediation planning is the familiar one of managing erosion to maintain the effectiveness of the cover. If the rate of erosion is controlled to the 2 to 3 mm/year range, the thickness proposed for the cover is likely to be sufficient for 300 to 1000 years. By effectively controlling erosion the thickness of the cover may even be slightly reduced without materially affecting performance. However limiting the erosion may be a challenge as observational experience at uranium mines in arid areas have indicated that various agents, including plants (which may mitigate wind erosion), have instead caused failure of cap integrity, well before the weathering has removed a major portion of its thickness.

The RESRAD model was also designed to evaluate water penetration and percolation into ground water, when unsaturated layers are relatively thin above saturated ones. However, with a groundwater depth of approximately 60 m, this was not considered significant enough to warrant incorporation in the analysis.

As far as radon emanation is concerned, USEPA supplemental guidance (USEPA 2002) states (as previously noted in section 3.3.2): *“…exposures to radon should be subject to the requirements for occupational exposure if the radon concentration exceeds the action level…”* Radon emanation rates and doses were briefly examined in the RESRAD sensitivity tests, the results indicated that the 70 cm clay layer alone is sufficient enough to reduce existing radon levels by at least six orders of magnitude (i.e. 1/1,000,000) - insignificantly low with the proposed cover in place. As such, the main ongoing design concern is that the integrity of the clay cap be maintained for many years (e.g., 200-1000 years). That means that plans for park use should also address the characteristics of a vegetative cover material that will serve to reduce erosion rates below those that would be likely with bare ground. On the other hand, this cover should not include species likely to have taproots that, in seeking water, would penetrate and compromise the integrity of the clay layer of the cover. Furthermore, the use of a riprap layer for the side slopes also offers excellent shielding capacity to protect those at the surface from the TENORM radiation forms other than radon.

The culmination of the obtained modeling results justified the existing high degree of confidence in the performance of the proposed cover. This gives enough reason to believe that as long as the clay cover remains in place, radon levels should remain insignificantly low. However, if some areas of the site are developed with building projects, this cover layer may be eliminated or greatly compromised. Section 5.2 presents general considerations when building/construction projects on the remediated site are being proposed.

Air Modeling for Remediation Planning

A new run of the AERMOD model was carried out to represent the benefits of the remediation cover plan. Although the RESRAD model contains a code for offsite air concentrations from radionuclides, AERMOD was preferred for maintaining data consistency and for the distinct advantages associated with it[8]. The resultant air patterns of annual air concentrations of fugitive dusts at the site and in the immediate vicinity are shown in Figures 4, 5 and 6 in Appendix B2.

As a final step, Figure 11 presents related contours that illustrate the patterns of estimated radiological inhalation exposures. These are annual average calculations assuming 30 years of exposure and 30-year total committed dose factors. For the specific hypothetical onsite receptors these values have to be reduced according to the fraction of a year that they are anticipated to experience the represented exposures. However, these specific receptor types also would often have a residence in the nearby area, so they may have a total annual exposure that is a sum of the fraction they receive on-site and the fraction they receive at home. For the reader’s convenience, information pertaining to surrounding land use (previously presented in Figure 4 of this document) is presented in Figure 9 below in a series with other figures.

Dose Modeling – Exposure Scenarios and Receptors for Post-remedial Conditions

With the proposed cover in place the **Maximum Offsite Resident** is now predicted to experience no more than 0.75 mSv/year (as opposed to 6 mSv/year). This single “worst case” location would be within IAEA guidelines. Most **Off-site Residences**, on the other hand, (including those close to the facility boundaries) were at least a factor of three lower than this maximum case; that is, the dose rates in the eastern neighborhoods would average 0.25-0.35 mSv/year if they were at home (or at a similar location with respect to the eastern boundary of the site) for 24 hours a day. However, it should be noted that if the topsoil used to cover the site is not quite as “clean” as that modeled, the predictions could be slightly higher. However, the result would still represent a major improvement over the present case.

[8] AERMOD offers the opportunity to model flow of elevated releases of material over the top of or around terrain features; the surface flow model was applied as it is the most representative given the present case of surface emissions.

Based on early public concerns, the exposures to the neighborhood of several particular on-site residential-type buildings on the south western side of the current stockpile region (virtually within the site) were reviewed, and according to the dose mapping previously presented had predicted exposures close to or above (but within +/- 20% of the IAEA dose rate guideline for adults of 1 mSv/year). Present understanding is that these buildings will not be inhabited (or even present) in the future, so they will not likely be a further concern. Regardless, with the proposed remediation cover soil in place, the updated prediction for these residences would be less than 0.5 mSv/year. This would make them safer for occupancy by families. In all cases the exposures have been calculated for a 30-year residency, so similar dose rates for shorter periods would also fall within the guidelines. In this case, especially, continued management of erosion would be the key to lowering all long-term dose predictions.

The **Park Visitor**, who is also identified to be a resident child, is the least exposed of the evaluated scenarios, due to the relatively short duration and limited frequency of assumed exposure times. The total annul exposure of < 0.03 mSv/year for this activity scenario is insignificant, especially when compared to the same individual's exposure while at home, if that residence is within a few hundred meters of the site boundary (as described above). The **Soccer Player** scenario was added for the current review, due to the fact that the corner of the field demonstrated higher exposure rates than any other locations within the boundaries of the Park area currently covered with 'dark soil'. In spite of that fact, the short total duration assumed for the player's exposure results in a low total dose commitment of 0.07 mSv/year.

The livery **Farm Market** area on the southeast edge of the stockpile area also required a careful analysis of potential exposures. Modeling results indicate inhalation dose rates might be close to the 0.5 mSv/year range, if occupied just 10 hours/day. However, the more precise calculation for the specific receptor location shows that the total dose, including the background levels expected at the location, would amount to 0.75 mSv/year - still below the 1 mSv/year limit for adult residents. It is not clear how long children would be present at this exact site. However, the lower inhalation volume rate for children (normally about ½ that of an adult) would also result in a long-term dose prediction below 0.5 mSv/year.

The future **Outdoor Worker** is assumed to regularly work in either the planned Eco-Park area (Area F), or in any adjacent remediated area developed for recreational purposes (e.g., Areas D, E, G) where maintenance activities would be routinely performed in the future. The post-remediation calculations show that this worker might receive a dose of < 0.41 mSv/year. This dose is below the IAEA guide limit for adult residents, even though as a (trained) worker, the applicable guideline is 20 mSv/year (IAEA 2014).

For the **Construction Worker** considered in this analysis, both the measurements reported for the simulation tests, as well as the short and long-term exposure doses calculated with the two models (SCREEN and AERMOD), indicate that the maximum annual levels should still be well within the IAEA 20 mSv guideline for trained workers, with a current maximum estimate equal to 6.66 mSv/year, due to potential exposure to uncovered materials during the course of construction work. It has been assumed that before or after remediation, construction work may involve digging through the cover layers into some of the highest concentration phosphate tailings or compressed fines which showed maximum soil concentrations (averaging close to 1154 Bq/kg), although this level of worker exposure is unlikely to continue for an entire year. A summary of key existing and post-remedial exposure scenarios are presented in Table 14.

Table 14. Comparison of Maximum Existing and Post-remedial Exposure Scenario Results

Scenario	Applicable IAEA Recommended Dose Limit (IAEA 1996)	Existing Conditions	Post-remedial Case
Off-site Resident	1 mSv/year (adult)	**5.95 mSv/year**	0.75 mSv/year
Park Visitor	0.5 mSv/year (children)	0.06 mSv/year	0.03 mSv/year
Soccer Player	0.5 mSv/year (children)	Not studied in initial assessment	0.07 mSv/year
Outdoor Worker	20 mSv/year (trained worker)	0.94 mSv/year; max. 5.45 mSv/year	0.41 mSv/year
Farm Market	1 mSv/year (adults) 0.5 mSv/year (children)	0.96 mSv/year	0.48 mSv/year

Figures 10, and 11 provide graphical information pertaining to receptor proximities to Area 3, existing and post-remedial effective doses, respectively. Figure 10 shows that several of the nearby homes are exposed to doses that exceed 1.0 mSv/year – the maximum recommended does according to IAEA Safety Guidelines (IAEA 1996, 2014). Figure 11, which models the post-remedial conditions, shows a maximum dose of 0.75 mSv/year – well below the safety threshold.

Figure 12 shows that large portions of the site contained average Uranium concentrations that exceeded IAEA regulatory exemption criteria (IAEA 2004). However, with the proposed cover in place, all of the areas assessed in the modeling exercise are anticipated to be well below the aforementioned threshold, as shown in Figure 13.

Figure 9. Stockpile proximity to likely receptors.

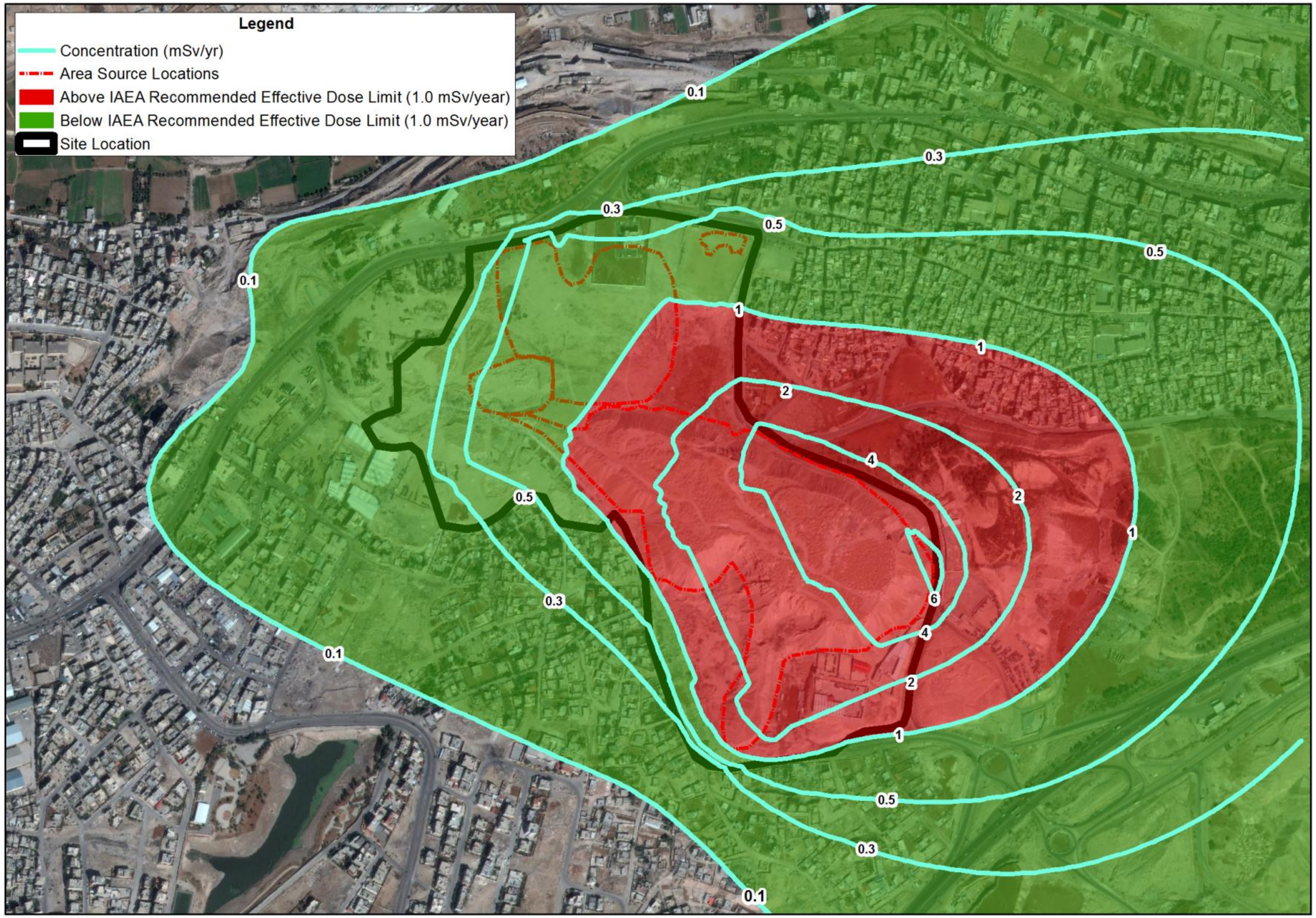

Figure 10. Effective doses based on air modeling of existing conditions.

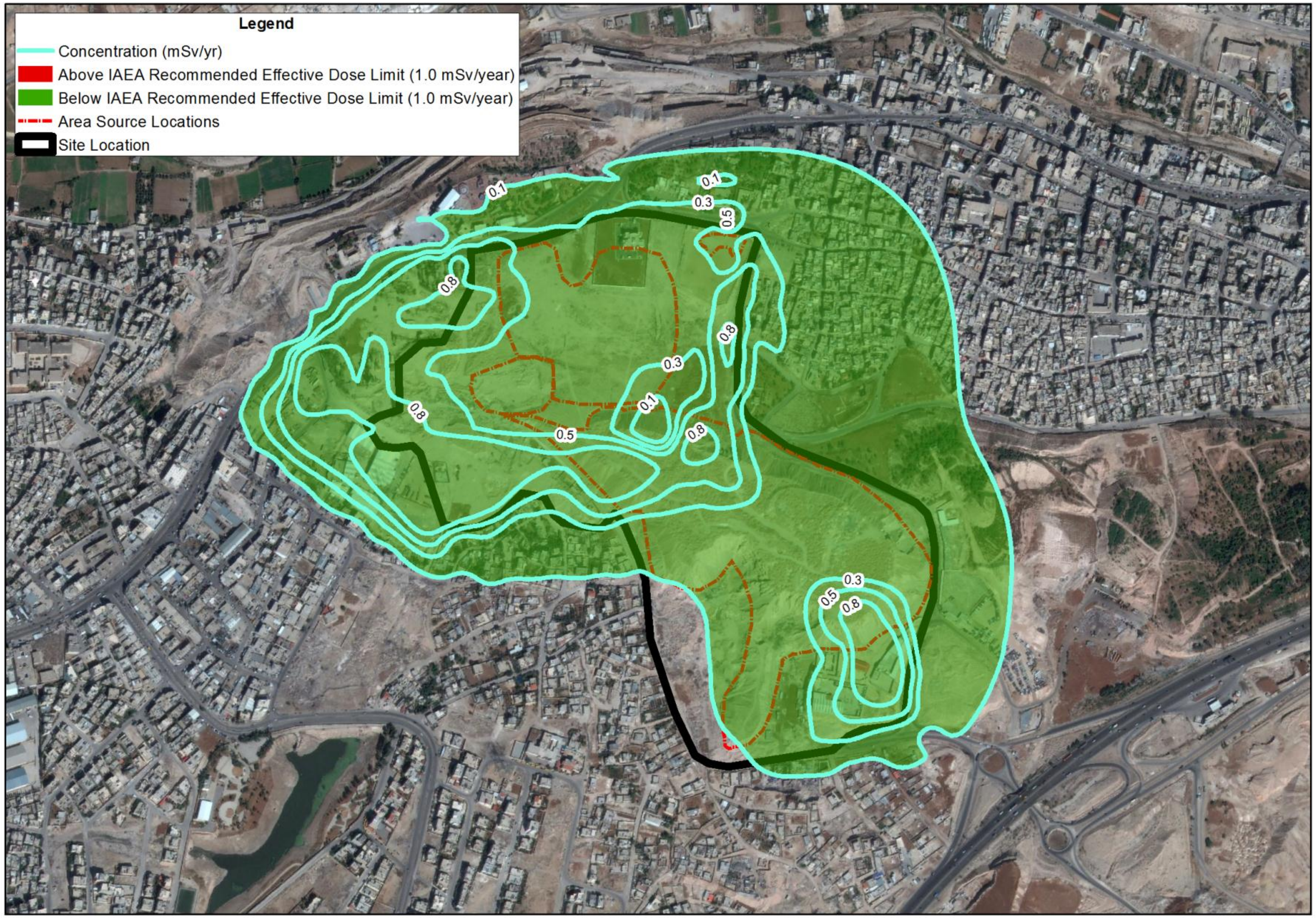

Figure 11. Effective doses based on air modeling of post-remedial conditions.

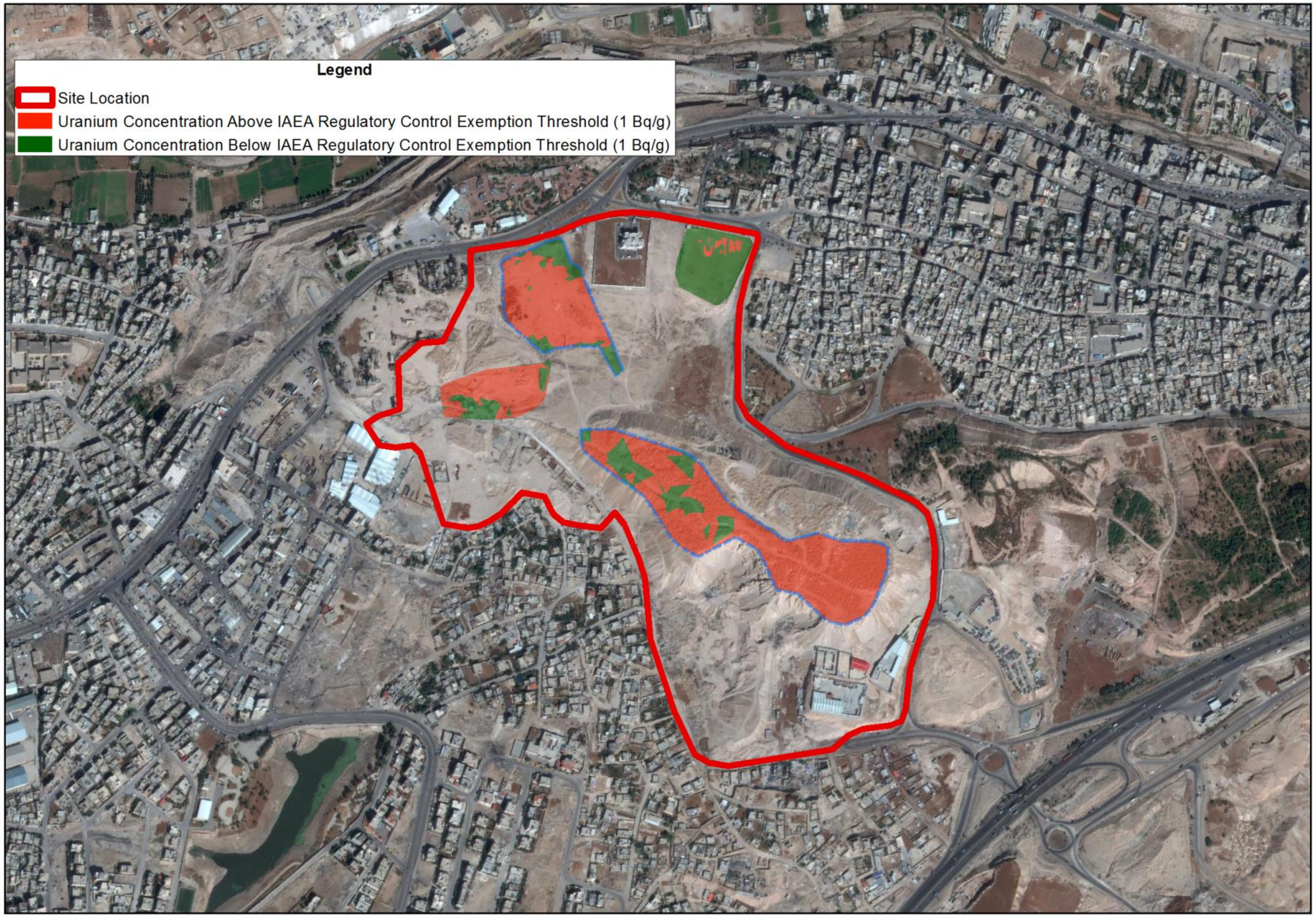

Figure 12. Uranium-238 concentrations at existing conditions (@ 15 cm).

Figure 13. Uranium-238 concentrations at post-remedial conditions.

Conclusions of Post-remedial Radiological and Air Modeling Exercise

The currently proposed remediation plan, which includes installation of a 70 cm clay cover layer after re-grading much of the site area, represents a way to improve the ability to re-use the site for a park and other purposes. It would also improve the control of airborne dust that now contains elevated trace levels of radioactivity. With the cover in place the committed dose levels for all of the neighbors and anyone working on the site area will improve by a factor of 3 to 5. This alone would make the site more appropriate for a wider range of future reuses.

The modeling assumption used in this update analysis, which incorporates use of the proposed cover design, is still intentionally health-conservative. However, future users of the site should compare actual planned site operations to the scenarios modeled in this study to gauge the relevance of the predicted dose commitments.

It is worth noting that according to IAEA Safety Guides (IAEA 1996, 2014), without the proposed remediation cover, both public and worker radiation exposures at Russeifah Area 3 would currently be subjected to the requirements of protective practices as they will most likely not receive the benefits of the remedial cover. Nonetheless, all of the present modeling results indicate the effectiveness of the proposed remediation cover in reducing long-term dose commitments to much more acceptable levels, consistent with IAEA guidelines (IAEA 1996, 2014). Due to the strong influence of the effective erosion rate upon the durability of this solution, it is recommended that the plan include a prescription for long-term monitoring of fugitive dust concentrations in the site vicinity, coupled with continuing erosion management plans. In this way the plan can periodically assess and limit cover removal in critical site areas to promote safe re-use of this phosphate storage site property.

4.3.2.5 Alternative Cover Designs

Redevelopment of Area 3 is restricted by numerous considerations[9] to safeguard the performance integrity of the remedial cover (base design) proposed in Section 4.3.2.2. Conclusions of case studies from the USEPA's reuse of abandoned mine lands (i.e. Superfund sites), indicate that generally sites such as Area 3 are generally well-suited for recreational reuse (USEPA n. d.). Redevelopment of Area 3 as a public park ensures that cover performance would not be compromised by irresponsible planning and construction activities on the remediated site. While landscape design for the remediated site is well beyond the scope of this document, alternative covers have been developed for installation alongside the envisioned hardscape and landscape architecture of the remediated site. Both cover designs are shown in Figure 14.

Landscape Cover Design

In the US, there is a large body of guidance for vegetating landfill caps developed by the USEPA and others. Most guidance documents suggest that the major concern with planting vegetation on top of a clay barrier layer or similar compacted soil layer is that the materials are prone to desiccation cracking over time (Waugh n.d.). Root systems of plants eventually grow into the desiccation cracks and further exacerbate the problem, increasing the permeability of the barrier layer and creating the potential for water infiltration and radon flux (EPA Ireland 1999). A potential layering system based on the guidance documents reviewed for vegetating landfill caps for use where vegetation is proposed on the landfill cap is provided below (listed in order from top layer to bottom layer):

[9] See Section 5 – 'Post-remedial Use and Development Recommendations and Section 6 – Challenges to Site Development'

- Topsoil layer (30 cm minimum)
- Subsoil layer (70-85 cm minimum for trees, 30 cm minimum for shrubs and grass)
- Water-permeable geotextile filter fabric layer
- Sand or gravel drainage layer (30 cm, permeability of $1x10^{-2}$ cm/s or greater)
- Geomembrane layer (60 mil minimum)
- Clay or other compacted soil radon/infiltration barrier layer (60 cm minimum, permeability of $1x10^{-7}$ cm/s or less)

The goal of the topsoil and subsoil layers is to support vegetation, prevent erosion, and provide storage of some precipitation until evapotranspiration occurs. The water-permeable geotextile filter fabric prevents contamination of the drainage layer with fine soils and helps prevent root growth downward. The drainage layer is designed to convey excess precipitation during large storm events, which is essential in a climate such as in Jordan, which is prone to sudden, intense rainfall. The geomembrane layer and clay layers provide a radon and infiltration barrier, help prevent desiccation cracking, and help prevent root growth into the barrier layer if desiccation cracking does occur. Similar cap designs have been employed in the western half of the US (e.g. Monticello, Utah) with success. A layering system such as described above has been proven to support vegetation while preserving the effectiveness of the radon/infiltration barrier layer.

Hardscape Cover Design

The relative impermeability of hardscapes in landscape architecture indicates that fewer considerations are needed when developing hardscapes atop the base design presented in Section 4.3.2.1 of this document. In order to support hardscape development, the base design is to be complemented with a 20-cm (0.2 m) base course layer, as shown in Drawing 7.

- Base course (20 cm)
- Sand or gravel drainage layer (30 cm, permeability of $1x10^{-2}$ cm/s or greater)
- Clay or other compacted soil radon/infiltration barrier layer (60 cm minimum, permeability of $1x10^{-7}$ cm/s or less)

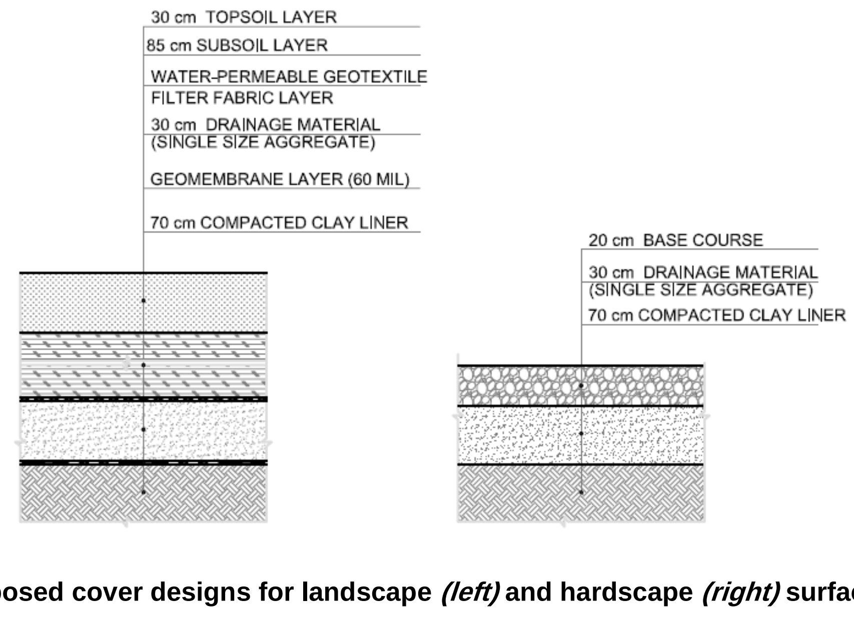

Figure 14. Proposed cover designs for landscape *(left)* and hardscape *(right)* surfaces.

4.3.3 Storm Water Management System

4.3.3.1 Design Strategy

Drainage systems are designed to protect the site from runoff generated from external catchments and urban development both within and surrounding the site boundaries.

The project site is a synthetic hill where the runoff of the surrounding drainage basins flows in away from the project area. No external wadis pass through the site as shown in the figure below. Furthermore, the low permeability of the riprap and clay covers is expected to produce significant volumes of runoff during rainfall events. In order to reduce the potential of flooding and extreme runoff, drainage system components were integrated into the stockpile cover. The relevant catchment and areas and flow calculations are presented in Appendix C. Based on these catchments, the storm water management system was designed to intercept and convey the generated runoff away from the site, while making use of the surrounding infrastructure.

The engineered storm water management system consists of a combination of pipe culverts, riprap protected variable-depth ditches and concrete chutes that have been integrated into the cover design and tie into the municipal drainage network.

4.3.3.2 Engineered Storm Water Management System

The concept behind the engineered drainage system plan (Appendix E, Drawing 8) is to intercept excessive runoff (particularly from the top face of the pile and side slopes covered with grouted riprap) and utilize site grading to channel water away from the site without causing any flooding to the surrounding areas. This is to be achieved by using the inclined surfaces to channel storm water towards the four concrete chutes along riprap ditches and the inclined terraces.

Concentrated runoff from the chutes will then be channelled through roadside riprap ditches before being intercepted by pipe culverts that link the engineered drainage system of Area 3 with the drainage infrastructure of Russeifah.

Flow calculations were derived taking into account 1) the exceptionally long service life of the remedial design; 2) post-remedial uses of the site; and 3) synergies with the urban infrastructure of the area. The designed service life of the remedial cover design (200-1000) years indicated that the project site would be affected by less frequent, more intense storms than what is typically designed for. Documentation and calculations for a design storm of 50 years are presented in Appendix C.

4.3.3.3 Riprap Ditches

A combination of side and variable depth ditches were incorporated into the design such that excess runoff could be collected from the top face of the main stockpile. The ditches will be composed of 20 cm-thick grouted riprap with 3H:1V slopes, as shown in the details presented in Drawing 9.

The side ditches, located along existing roads around the site in addition to the top face of the pile, will have a depth of 0.5 m.

As shown in Drawing 8, variable depth ditches (VDD) are to be installed along the southern portion of the top face of the pile (VDD 1) and along the main road (VDD 2) immediately adjacent to the northeastern aspect of the stockpile (with maximum depths of 1.1 m and 0.8 m, respectively).

4.3.3.4 Concrete Chutes

Four reinforced concrete chutes have been strategically located along the side slopes of the main stockpile to collect and concentrate runoff from the engineered terraces, and discharge into roadside ditches and ultimately into the municipal drainage network. Chute plans, profiles and sections are presented in Drawing 11, while the structural details of chute reinforcement are presented in Drawing 12.

4.3.3.5 Drop Inlet Culverts

The impermeability of most surfaces in Area 3 is likely to create volumes of runoff well-above the capacity of the existing municipal drainage infrastructure. Currently, only one 700 mm diameter culvert along the project site boundary – flow calculations indicated that two additional culverts would be necessary to effectively channel excess runoff away from the remediated site and prevent flooding in the immediate vicinity. A 900 mm diameter culvert needed to be installed adjacent to the existing culvert to channel runoff from chutes 1 & 2, while a second 700 mm diameter culvert was designed to intercept flows from chutes 3 & 4. Drop inlet details for the new culverts are presented in Drawing 9, whereas culvert details are shown in Drawing 10.

5 POST-REMEDIAL USE AND DEVELOPMENT RECOMMENDATIONS

It is worth noting that most UMTRA disposal sites have not been faced with urban encroachment as is the case in Area 3. The majority of UMTRA disposal sites were observed to be situated in remote locations away from urban settlements. The close proximity of urban settlements around the project area highlights the need for a new set of considerations when viewed through the lens of post-remedial land reclamation/reuse. Land-ownership of Area 3 is divided among several public entities and the now-privatized Jordan Phosphate Mines Company. Land-ownership is likely to change over the course of the service life of the remedial cover, indicating that development activities are likely to vary in nature. In order to safeguard the long-term functionality of the remedial design and protect public interests, a set of development recommendations and considerations were developed by the Project team. Despite the fact that site-development is well beyond the scope of this remedial design, it was incumbent that the Project provide some form of guidance to site developers in light of the comprehensive assessments undertaken during the study period, in addition to an underlying need to harmonize synergies between the remediated site and the surrounding urban fabric of Russeifah.

5.1 Vegetation and Landscaping

Current trends in UMTRA disposal site cover design involve the use of thick layers of top-soil and the use of natural vegetation to “integrate” ecosystem components and promote cover sustainability. One notable example of a vegetated UMTRA cover is located in Monticello, Utah. The alternative cover design in Monticello performed well during a 7-year period of monitoring (2000-2007) by the USDOE Office of Legacy Management and the USEPA (Waugh, Kastens, Sheader, Benson, Albright, & Mushovic 2008).

In addition to improving aesthetic conditions of Area 3, incorporating vegetation into cover designs serves as a valuable means to:

- Control the flow of water (reduce the percolation of precipitation into the underlying tailings; prevent extreme runoff by promoting soil water storage and plant evapotranspiration).
- Prevents unwanted biointrusion by presenting itself as a controlled biological ecosystem

According to Waugh et al. (2008), the effectiveness of such alternative designs is heavily contingent on the interplay between local plant ecology, soil hydrology, and climatology. However, it is worth reiterating that in the absence of landscape design that considers impacts on the underlying clay layer; the performance integrity of the cover design is likely to be greatly compromised. With this in mind, suitable species were identified for potential landscaping activities on the remediated site. A preliminary technical memo was developed and can serve as a guiding document to landscaping all site areas capped with the landscape soil cover – provided that more detailed research and field studies are undertaken before final species selection. The complete report can be found in Appendix D.

5.1.1 Methodology

Candidate species were drawn from a list of 128 plant species previously identified for use at a constructed treatment wetland project in Al Zarqa, Jordan, and was supplemented with vegetation identified through online searches and journal article reviews. Criteria for identifying and ranking candidate species included:

- Native status;
- Water requirements and interplay with local climatological conditions;
- Soil stabilization potential;
- Root depth;
- Salinity tolerance;
- Ornamental quality and aesthetic appeal; and
- Maintenance requirements

Species with strong soil erosion control properties and strong root networks (albeit with shallower mature root depths) were prioritized and evaluated alongside other factors such as the plant’s ability to provide shade, aggressiveness, and wind-breaking properties.

5.1.2 Working Assumptions

The criteria outlined above were considered under the assumption that plants will be irrigated with municipal water. Although this was an assumption as part of our research, we understand that irrigation water is at a premium in this region and therefore required water uptakes were seriously considered when evaluating vegetation.

The region’s climate is hot and dry with annual precipitation in Jordan of about 24 cm, where June, July, and August are often without rainfall. Much of the annual rainfall is contributed by violent storms in the winter months. Hot, dry, and dusty winds are also characteristic of the region. Pictures of the Site and surrounding area were provided and exhibited the general lack of vegetation and the dryness of the area.

5.1.3 Recommendations and Conclusions

Research activities included a review of several case studies where vegetated caps were used in the United States of America (US). Vegetation for the cover systems were used to promote transpiration and minimize erosion by stabilizing the surface of the cover. Grasses (wheatgrass and clover), shrubs (rabbitbrush and sagebrush), and trees (willow and hybrid poplar) have been used on evapotranspiration (ET) covers in the US. Evapotranspiration covers are a type of landfill cover that prevents water infiltration using vegetation and water storage in the topsoil/subsoil layer as opposed to a typical drain layer/impervious layer.

A mixture of native plants consisting of warm- and cool-season species are usually used, as native vegetation is more tolerant than imported vegetation to regional conditions, such as extreme weather and disease. The combination of hotter- and cooler-season species enhances plant water uptake and supportive storage throughout the entire growing season, which enhances transpiration. In addition, native vegetation is usually planted, because these species are less likely to disturb the natural ecosystem (USEPA 2000). Similar recommendations to use native and diverse vegetation are applicable to the proposed cap installation at the Russeifah Area 3 Site.

Based on the research and combined with understandings of the site constraints and desired criteria, the following species from the tabulated results are recommended for potential park vegetation. At this time, these species are only provided for further evaluation and must undergo additional evaluation prior to final selection and application. Additional information is included in tables 1, 2, and 3 of Appendix C.

Recommended Grass Species *(Top three species listed from highest to lowest):*

- *Cynodon dactylon*
- *Dichondra repens*
- *Lolium perenne*

Grass species research yielded 8 results with approximate qualitative root depths for species tabulated (Appendix D, Table 1). *Cynodon dactylon* has high stabilization potential, is heat and drought tolerant, and requires little maintenance. *Dichondra repens*, a lawn alternative, has high stabilization potential, adapts to warm climates, and requires infrequent maintenance. *Lolium perenne* has high stabilization potential and can tolerate drought.

Recommended Shrubs Species *(Top three species listed from highest to lowest):*

- *Bassia indica (Kochia indica)*
- *Nerium oleander*
- *Tamarix spp.*

Shrub species research yielded 16 results with approximate root depths for 8 of the species tabulated (Appendix D, Table 2). *Bassia indica* has good stabilization potential and can grow in salt-affected land. *Nerium oleander* has high stabilization potential and is salt-tolerant and hardy. *Tamarix spp.* may have some stabilization potential and salt tolerance.

Recommended Tree Species *(Top four species listed from highest to lowest):*

- *Oleana europaea*
- *Punica granatum*
- *Salix spp.*
- *Pistacia vera*

The majority of native tree species identified tend to root deeply due to climate conditions (Appendix D, Table 3). It is unlikely that a shallower-rooting, non-native tree would flourish well in this climate. Significant additions of topsoil and fill material would need to be installed under an altered cap design in order to support tree growth under the Site restraints. Of the 17 species of trees that the research yielded, only two species reported the potential for relatively shallow roots. *Oleana europaea* has high stabilization potential, is drought tolerant, and characterized by shallow roots. *Punica granatum* has high erosion control potential, is drought tolerant, grows in arid environments, and may be shallow-rooted. *Salix spp.* has high soil stabilization potential and has been reportedly used in the rehabilitation of mines sites. *Pistachio vera* has high soil stabilization potential and has been cultivated in arid environments.

While the research revealed some potential candidates for vegetation of the Site, it must be reiterated that these results must undergo additional evaluation prior to final selection and application. Additionally, preliminary assessments indicate that inclusion of trees on the vegetated cap would not be recommended. Trees will require more water than grass and shrub covers, are likely to compromise the clay barrier layer due to deep root migration, and are more susceptible to death, damage and windblow.

In all cases, however, additional layers of topsoil will be needed to support plant growth and reap the associated benefits of ET/vegetative covers. The required thickness of the additional layers will vary depending on the type of vegetation selected for landscaping; this equates to roughly 30-40 cm to support most of the recommended shrub species and roughly 70-95 cm to support the recommended tree species. Furthermore, selected topsoils should have sufficient organic matter and content to support native vegetative growth and should not be excessively saline or sodic (unless contractors opt for selecting salt-tolerant species).

Nonetheless, the possibility that root systems of selected plants would penetrate the clay layer still exists. While the alternative design in Monticello, UT has incorporated the use of geosynthetic materials as a core component of the remedial cover design there has been very little research done to conclusively determine the long term effectiveness of such materials in light of the designed service life. In order to ensure the sustainability of cover performance, it is highly recommended that patches of geosynthetic liners be placed prior to planting trees (i.e. on a tree-by-tree basis). Adopting such an approach would ensure localized and targeted clay protection without compromising the functionality of core design components over the long-term.

5.2 Building Activities, Utilities and Infrastructure

The presence of the phosphate ore, and the natural uranium and thorium contained therein, constitutes a radon source that could result in hazardous future indoor air concentrations. Based upon the previous results from the radon sampling program in 2012/2013, the indicated radon emanation from the soils and ore at the site at levels do not currently represent a significant hazard from outdoor exposures to workers and the public. Thus, the risk from a slight leakage of radon from the cap in the future is not likely to be a severe problem for the levels of TENORM activity present at this site. However, radon concentrations in structures vary greatly depending upon the underlying geology, the structure, and weather conditions, among other factors. Therefore, the addition of a capping project that also minimizes future radon emissions will help to avoid, or at least minimize future problems.

Excavation and construction on the remediated site would likely expose and compromise the radiological protection provided by the cover. Such concerns also apply to the installation of utility services, such as field lighting, bathrooms, concession stands, water distribution, and sewerage (USEPA 2001). Cover penetration would result in radon levels and resultant exposures (to workers and the general public) that vary greatly due to their dependence on variables such as building construction, ventilation, and underlying geology. While indoor radon levels were not assessed during the previous and current studies, there is enough reason to believe that hazardous indoor concentrations of radon are likely in lower building levels (e.g. basements, underground parking spaces, etc.). This would necessitate consideration of additional ventilation in these floors to dissipate radon and prevent its accumulation in confined areas. Nonetheless, penetrating the remedial cover is to be avoided to the extent possible and the introduction and enforcement of ‘no-dig policy’ is highly recommended. In reference to the recreational reuse of hazardous waste containment sites, the USEPA (2001)[10] states that:

‘If a building must be located on the cover system to support planned reuse, temporary or movable structures such as small sheds or trailers used in place of permanent structures have proven to be effective’

The radioactive context of Area 3 requires strict adherence to such recommendations.

5.3 Paved Surfaces and Trails

According to the USEPA, almost all reuse sites will include paved surfaces used for a variety of purposes such as parking lots, roads, stairways, and trails. The addition of the base course layer into the remedial cover design is intended to serve as a proper foundation for such surfaces, minimizing the need for further earthwork at the expense of damage to the remedial cover.

5.4 Recommendations and Conclusion

Many locations of the site are already witnessing development activities that could, in some cases restrict the ‘reach’ of the remedial cover design. As of September 29th, 2014, the project site currently accommodates the construction of a fiberglass factory near the south-eastern part of the site adjacent to the vehicle impoundment area – in addition to the recently completed building police building (near the soccer area and the proposed site of the Ministry of Environment (MoEnv Eco-Park) and existing farmers market. These ad-hoc developments are clear indicators of local community development needs; and are being constructed in the absence of the needed precautions. Therefore, post-remedial development activities need to be regulated and controlled to ensure public well-being, the long-term functionality of the remedial design and its integration within the urban fabric of Russeifah.

The ambiguous nature of post-remedial development activities in Russeifah Area 3 and the complex interplay between land-ownership and the relevant actors necessitates a more holistic approach to developments on the site. Based on the results of the existing and post-remedial radiological assessments, it is desirable that post-remedial land-use take into account that receptors are least exposed during what can be described as ‘transient, short-term or recreational’ activities (i.e. park visitors, soccer players, market visitors etc.). This stems from the fact that exposure doses are heavily contingent on the duration in which a receptor is exposed to radioactivity.

[10] United States Environmental Protection Agency, *“Reusing Superfund Sites: Recreational Use of Land Above Hazardous Waste Containment Areas”* 2001

As part of the Superfund Redevelopment Initiative (SRI), the USEPA issued a guidance document entitled "*Meeting Community Needs, Protecting Human Health and the Environment: Active and Passive Recreational Opportunities at Abandoned Mine Sites*[11]" (USEPA n. d.). It is in this document that EPA highlights how well suited sites such as Area 3 are for recreational reuses, citing that in-situ waste containment typically incorporates vegetated cover systems that are compatible with a variety of recreational uses. As noted previously in this report, the Jordanian Ministry of Environment has proposed the development of an Eco-Park on an area of approximately 100 dunums (10 hectares) in the northern part of Area 3. The park is currently in the planning phase and is a collaborative effort between the Ministry of Environment and the Greater Amman Municipality. The proposed park project aligns well with the redevelopment scenarios set forth by several EPA documents – provided that critical cover components are left unexposed and safeguarded for the long-term. Furthermore, the guidance documents differentiate between two categories of recreational prospects – active[12] and passive[13] recreation. Both types of activities are commonly associated with economic and social benefits to local communities and can be located together effectively, despite the fact that passive recreation activities are typically linked with natural ecosystems and landscapes. Table 15 presents examples of passive and active recreational activities that are deemed well-suited for the urban context of Russeifah Area 3.

Table 15. Examples of Active and Passive Recreation Activities Compatible with the Urban Context of Area 3

Active Recreation	Passive Recreation
Soccer	Picnicking
Skateboarding and Rollerblading	Walking
Paintball	Bicycling
Softball	Running/Jogging
Tennis	Climbing
Basketball	Viewing decks

References: *'Meeting Community Needs, Protecting Human Health and Environment: Active and Passive Recreational Opportunities at Abandoned Mine Lands',* (USEPA, n.d.*); 'Reusing Superfund Sites: Recreational Use of Land above Hazardous Waste Containment Areas'* (USEPA 2001)

Both forms of recreational activities bring a wide array of social and economic benefits to the surrounding communities. In urban contexts in particular, recreational facilities can enhance urban revitalization efforts while promoting local economic growth, investment, and improved community health (USEPA n. d.). In the case of Area 3, it is recommended that passive recreational activities be pursued throughout the site; particularly atop the main stockpile to not only maintain critical cover components, but also to capitalize on the unique viewing perspectives from the top the pile.

In conclusion, guidance documents published by the USEPA (as cited in Table 15) highlight the fact that abandoned mine lands (such as Area 3) offer unique opportunities for recreational reuse activities. However, site safety and environmental concerns must be of primary and central focus during reuse planning to help guarantee the compatibility between the remedial design and reuse options. Furthermore, the USEPA notes the importance of key components to the successful reuse of abandoned mine lands (AML) as follows:

[11] Abandoned Mine Lands (AMLs): "*Lands, waters, and surrounding watersheds where extraction, beneficiation, or processing of ores and minerals has occurred; these also include sites where mining and mineral-processing waste were disposed of or deposited.*" (USEPA n. d.)
[12] Active recreation: "*A structured individual or team activity that requires the use of special facilities, courses, fields, or equipment*." (USEPA n. d.)
[13] Passive Recreation: "*Recreational activities that do not require prepared facilities like sports fields or pavilions."* (USEPA n. d.)

1. Sustained community involvement (that goes beyond an inclusive stakeholder processes);
2. Effective site reuse process (including visioning sessions); and
3. Continuous oversight and coordination between regulatory bodies and other relevant agencies (i.e. MoEnv, JNRC, site maintenance team, etc.).

Effective reuse of the site is not without its set of challenges (discussed in section 6). However, it is believed that undertaking the aforementioned issues would help to reduce or avoid altogether potential disruptions to the remediation and redevelopment of Russeifah Area 3.

6 CHALLENGES TO SITE DEVELOPMENT

The complex legal, economic, and environmental forces at the Russeifah site have influenced the remediation strategy and will likely shape redevelopment efforts. Outstanding issues include:

- JPMC's right to ownership of the extracted ore and possible disruption of remedial activities
- Financial responsibility for site clean-up
- Long-term involvement of JNRC

JPMC's license to mine phosphate in Russeifah is expired and they are not trying to obtain an extension nor will the government allow them to mine there anymore. The current debate is related to the phosphate ore that is already excavated and piled in Area 3. JPMC till the date of this report continues to claim ownership of this ore but does not have a clear plan of what and how this material will be utilized. In a recent letter to MoEnv, JPMC promises to expedite the process of determining what they will end up doing with this ore material and if it will be feasible for them to utilize it.

As for financial responsibility of the remediation, the privatization of the JPMC, has added ambiguity to whom should bear the incurred costs of the site's remediation. The agreement between the government and investors exempted JPMC from clean-up costs incurred prior to 2006 creating a legal-gray area with regards to cost of remediation.

Upon implementation of the design – and according to the IAEA's Safety Guides on Occupational Radiation Protection, the long-term involvement of the JNRC in post-remedial land-use will likely shape the future development activities. Furthermore, the United States Nuclear Regulatory Commission recommends (as a minimum) annual site inspection by the government agency responsible for the long-term care of the site – with the objective of confirming the sites integrity and identifying the need (if any) for maintenance and monitoring of the site.

7 COST ESTIMATE

A cost estimate and Bill of Quantities (BOQ) for the remediation plan for Russeifah Area 3 were developed for the various components of the remedial design. The cost estimate for Area 3 (Phosphate stockpile) rehabilitation constitutes the following components:

1. Earthwork (for slope stabilization and site preparation; including site access, excavation, reshaping, embankment construction and reinforcement)
2. Grouted riprap for stabilizing side slopes and
3. Infrastructure (including the ramp and fencing)
4. Protection works for the abandoned dwellings (i.e. retaining walls)
5. Drainage works (i.e. construction of chutes and ditches)
6. Hardscape and landscape remedial cover components (assuming 70% hardscape and 30% landscape coverage)

The overall cost for the rehabilitation of Area 3 (Phosphate stockpile) was estimated to reach a total of $16,029,345. The detailed cost estimate and BOQ can be found in Appendix F.

REFERENCES

42 United States Code (U.S.C.) §7901 et seq. (1978). *Uranium Mill Tailings Radiation Control Act*.

Jordanian Environmental Protection Law No. 52 (2006).

Arab Center for Engineering Services. (2013). *Russeifah Site Geotechnical Services.* Amman.

Crow, P. (November 2005). *The Influence of Soils and Species on Tree Root Depth.*

Environmental Protection Agency, Ireland. (1999). *Landfill Manuals: Landfill Restoration and Aftercare.*

Gaglio, M. D., Mackay, W. P., Padilla, D., Webb, R., & LeMone, D. V. (2001). The Effectiveness of Biobarrier Layers Within Protective Caps at Preventing Penetration of Waste Sites by the Harvester Ant Pogomyrmex Salinus Olsen (Hymenoptera: Formicidae). *Waste Management.* Tucson: University of Texas.

International Atomic Energy Agency. (1996). *International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Standard Series No. 115.* Vienna: IAEA.

International Atomic Energy Agency. (1999). *Occupational Radiation Protection.* Vienna: IAEA.

International Atomic Energy Agency. (2002). *Management of Radioactive Waste from the Mining anf Milling of Ores, Safety Series No. WS-G-1.2.* Vienna: IAEA.

International Atomic Energy Agency. (2004). *Application of Concepts of Exclusion, Exemption and Clearance, Safety Standards Series No. RS-G-1.7.* Vienna: IAEA.

International Atomic Energy Agency. (2004). *Occupational Radiation Protection in the Mining and Processing of Raw Materials, Safety Standard Series No. RS-G-1.6.* Vienna: IAEA.

International Atomic Energy Agency. (2014). *Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards.* Vienna: IAEA.

Jordan Phosphate Mines Company. (n.d.). *About Us*. Retrieved August 7, 2014, from Jordan Phosphate Mines Company: http://www.jpmc.com.jo/en/node/80

Konno, M. (1987). Radiation Shielding Concretes. *The International Nuclear Information System (INIS)*. Tokyo: International Atomic Energy Agency.

Lommler, J. C., Chen, P. K., Artiglia, E., Guros, F. B., Bridgeman, B., & Cox, S. (1999). DOE UMTRA Project Disposal Cell Design Summary. *WM'99 Conference.*

Maine Department of Environmental Protection: Bureau of Land and Water Quality. (2003). *Maine Erosion and Sediment Control BMPs.* Augusta: Maine Department of Environmental Protection:.

Reith, C. C., & Caldwell, J. A. (1990). *Vegetative Covers for Uranium Mill Tailings.* Albuquerqe: Jacobs Engineering Group Inc.

S. Cohen & Associates. (2010). *Risk Assessment Revision for 40 CPR Part 61 Subpart W - Radon Emissions from Operating Mill Tailings.* Washington, D.C.: United States Environmental Protection Agency.

S. Cohen & Associates. (2010). *Risk Assessment Revision for 40 CPR Part 61 Subpart W - Radon Emissions from Operating Mill Tailings.* Washington, D.C.: U.S. Environmental Protection Agency.

(2001). Case Studies of Management and Disposal of Mill Tailings and Wastes. In J. H. Saling, & A. W. Fentiman, *Radioactive Waste Management* (Second ed., pp. 277-288). New York, NY, United States of America: Taylor & Francis.

Schenk, H. J., & Jackson, R. B. (2002). Rooting depth, lateral root spreads and below-ground/above0ground allometries of plants in water limited ecosystems". *Journal of Ecology*, 90, 480-494.

Smith, G. M., & Weston, R. F. (1999). Evolution of Disposal Cell Cover Design Used for Uranium Mill Tailings Long-term Containment.

United States Environmental Protection Agency. (2000). Soil Screening Guidance for Radionuclides: Technical Background Document. Washington, D.C.

United States Environmental Protection Agency. (2001). *Reusing Superfund Sites: Recreational use of Land Above Hazardous Waste Containment Areas.* Washington, D.C.: USEPA.

United States Environmental Protection Agency. (2002). *Supplemental Guidance for Developing Soil Screening Levels for Superfund Sites.* Washington, D.C. .

United States Environmental Protection Agency. (2013, February 13). *Radon*. Retrieved August 26, 2014, from Radiation Protection: http://www.epa.gov/radiation/radionuclides/radon.html

United States Environmental Protection Agency. (n.d.). Health and Environmental Protection Standards for Uranium and Thorium Mill Tailings. *Title 40 Code of Federal Regulations (CFR) Part 192*.

United States Environmental Protection Agency. (n. d.). *Meeting Community Needs, Protecting Human Health and the Environment: Active and passive recreational Opportunities at Abandoned Mine Lands.* USEPA.

United States Environmental Protection Agency. (n. d.). *Meeting Community Needs, Protecting Human Health and the Environment: Active and passive recreational Opportunities at Abandoned Mine Lands.* USEPA.

United States Environmental Protection Agency, Office of Research and Development. (2000). *Introduction to Phytoremediation.* Washington, D.C.: United States Environmental Protection Agency.

United States Nuclear Regulatory Commission. (n.d.). 10 CFR Part 40: Appendix A - Criteria Relating to the Operation of Uranium Mills and the Disposition of Tailings or Wastes Produced by the Extraction or Concentration of Source Material from Ores Processed Primarily for their Source Material Content. Washington, D.C., United States of America.

United States Nuclear Regulatory Commission. (2014, August 25). 10 CFR Part 40. Washington, D.C., United States of America.

USAID. (2013). *Russeifah Area 3 Ore Stockpile Radiological Assessment, Water Reuse and Environmental Conservation Project.* USAID.

Wanielista, M. P., Kersten, R., & Eaglin, R. (1997). *Hydrology: Water Quanity and Quality Control.* New York: Wiley.

Waugh, W. (2004). *Design, Performance, and Sustainability of Engineered Covers for Uranium Mill Tailings.* Reston, Virginia.

Waugh, W. J., Kastens, M. K., Sheader, L. R., Benson, C. H., Albright, W. H., & Mushovic, P. S. (2008). Monitoring the Performance of an Alternative Landfill Cover at the Monticello, Utah, Uranium Mill Tailings Disposal Site. *Waste Management.* Phoenix.

ADDITIONAL BIBLIOGRAPHY

Crow, P. (November 2005). *The Influence of Soils and Species on Tree Root Depth.*

Gaglio, M. D., Mackay, W. P., Padilla, D., Webb, R., & LeMone, D. V. (2001). The Effectiveness of Biobarrier Layers Within Protective Caps at Preventing Penetration of Waste Sites by the Harvester Ant Pogomyrmex Salinus Olsen (Hymenoptera: Formicidae). *Waste Management.* Tucson: University of Texas.

Jordan Phosphate Mines Company. (n.d.). *About Us*. Retrieved August 7, 2014, from Jordan Phosphate Mines Company: http://www.jpmc.com.jo/en/node/80.

Reith, C. C., & Caldwell, J. A. (1990). *Vegetative Covers for Uranium Mill Tailings.* Albuquerqe: Jacobs Engineering Group Inc.

Schenk, H. J., & Jackson, R. B. (2002). Rooting depth, lateral root spreads and below-ground/above-ground allometries of plants in water limited ecosystems". *Journal of Ecology*, 90, 480-494.